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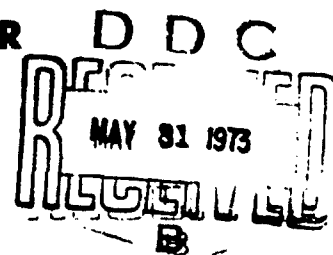
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AVSCOM PROJECT NO. 72-40  
USAASTA PROJECT NO. 72-40

## LIMITED PERFORMANCE TESTS CH-54B (TARHE) HELICOPTER

FINAL REPORT



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UNITED STATES ARMY AVIATION SYSTEMS TEST ACTIVITY  
EDWARDS AIR FORCE BASE, CALIFORNIA 93523

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## **ABSTRACT**

The United States Army Aviation Systems Test Activity conducted a limited performance evaluation and airspeed envelope expansion of the Sikorsky CH-54B (Tarhe) helicopter at Edwards Air Force Base and Bishop, California, during the period 25 October to 22 November 1972. Hover performance, level flight performance, airspeed calibration, and envelope expansion testing were conducted without the engine air particle separator installed. Testing required 13.6 productive flight hours. At takeoff power, the standard-day out-of-ground-effect and in-ground-effect (10-foot) hover ceilings were 6600 and 9050 feet, respectively, at maximum gross weight (47,000 pounds). The hover ceiling on a 35°C day, in ground effect, was 4900 feet at maximum gross weight. Level flight performance was obtained over a gross weight range of 26,070 to 29,990 pounds and a density altitude range of 5580 to 11,580 feet. The airspeed for best endurance was nominally 65 knots true airspeed and the never-exceed airspeed (101 knots calibrated airspeed) was the long-range cruise speed. A 33-percent increase in specific range could be achieved by operating with one engine after reaching cruise altitude. Airspeeds up to 125 knots calibrated airspeed were flown during the level flight, unaccelerated airspeed envelope expansion with no undesirable aircraft characteristics. No deficiencies or shortcomings were observed. The winch load indication system installed in the CH-54B enhanced sling load operations and should be installed in all cargo helicopters with a sling load capability. Further testing is recommended to obtain performance data with the engine air particle separator installed and to determine stability and control characteristics, structural loads, and fatigue life of dynamic components at airspeeds above the current never-exceed airspeed (101 knots calibrated airspeed).

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# **INTRODUCTION**

## **BACKGROUND**

1. In January 1971, the United States Army Aviation Systems Test Activity (USAASTA) was requested by the United States Army Aviation Systems Command (AVSCOM) (ref 1, app A) to determine airworthiness and flight characteristics of the CH-54B Tarhe helicopter. The USAASTA test plan (ref 2) was submitted in July 1971 and testing began on 16 August 1971. An AVSCOM letter dated 23 November 1971 (ref 3) amended the test request and imposed additional requirements for airspeed envelope expansion, airspeed calibration with engine air particle separators (EAPS) installed, and limited performance testing. An AVSCOM message (ref 4) directed that the envelope expansion and limited performance evaluation be conducted as a separate project to expedite reporting on the instrument-flight-rules (IFR) portion of the original project.

## **TEST OBJECTIVES**

2. The objectives of the CH-54B envelope expansion and limited performance evaluation were as follows:

- a. To expand the airspeed envelope of the aircraft in the clean configuration.
- b. To conduct an airspeed calibration with the EAPS installed.
- c. To conduct limited hovering and level flight performance.

## **DESCRIPTION**

3. The CH-54B helicopter, manufactured by Sikorsky Aircraft, is a twin-turbine, all metal, flying crane with a design gross weight of 47,000 pounds. The helicopter is designed to carry a detachable pod for transporting personnel and/or cargo, utilizing either four-point or single-point suspension. The four suspension points, which are located symmetrically around the center of gravity (cg), serve as attachment points for the load leveling system. The single-point hoist, located at the cg, consists of a hydraulically powered winch, cable, and cargo hook with a 25,000-pound capacity. There are 32 structural hardpoints on the fuselage of the aircraft which may be used to carry various loads.

4. The aircraft is powered by two Pratt and Whitney axial-flow gas turbine engines (model number T-73-P-700), each rated at 4800 shaft horsepower (shp), installed standard-day, sea-level conditions. (The dual-engine power available is derated to 3950 shp per engine due to transmission limitations.) The engines are mounted side-by-side on top of the fuselage. Engine torque is transmitted through a system

of gearboxes and drive shafts to the main and tail rotors. The main rotor consists of a fully articulated hub and six blades. The tail rotor consists of a rotor head and four blades. An auxiliary power plant is located aft of the main gearbox, and is used for ground starting of the engines and ground operation of the hydraulic and electrical systems. A complete aircraft description is included in USAASTA Final Report No. 71-01 and the operator's manual (refs 5 and 6, app A), and aircraft dimensions and design data are presented in appendix B.

### SCOPE OF TEST

5. The airspeed envelope expansion and limited performance evaluation were conducted at Edwards Air Force Base and Bishop, California, during the period 25 October to 22 November 1972. Thirteen test flights were conducted for a total of 13.6 productive hours. Test conditions are listed in table 1. Nominal rotor speeds were 185 and 193 rpm and the cg was mid for all tests. The flight restrictions and operating limitations contained in the operator's manual (ref 6, app A) were observed during this test. In addition, limitations on the airspeed envelope expansion were imposed by AVSCOM in a safety-of-flight release (ref 7). No data were obtained with the EAPS installed due to unavailability of equipment during the time frame of testing allotted by AVSCOM.

Table 1. Test Conditions.

Type of Test	Nominal Gross Weight (lb)	Nominal Density Altitude (ft)	Nominal Calibrated Airspeed (kt)
Hover performance <sup>1</sup>	<sup>2</sup> 24,000 to 47,000	1000 to 10,000	Zero
Level flight performance	26,000 to	5000 to 12,000	25 to 105
V <sub>NE</sub> expansion	27,000	3000, 6000, and 9000	90 to 125

<sup>1</sup>Wheel height: 10, 20, 30, 50, 70, and 145 feet.

<sup>2</sup>Includes cable tension.



## METHODS OF TEST

6. Established flight test techniques and data reduction procedures were used (ref 8, app A). The test methods are briefly described in the Results and Discussion section of this report. Data reduction techniques used are described in appendix C. Flight test data were obtained from test instrumentation displayed on the pilot instrument panel and recorded on magnetic tape. A detailed listing of the test instrumentation is presented in appendix D.

## CHRONOLOGY

7. The chronology of the CH-54B airspeed envelope expansion and limited performance evaluation is as follows:

Test directive received	17	October	1972
Test started	25	October	1972
Test completed	22	November	1972

## RESULTS AND DISCUSSION

### GENERAL

8. Hover performance testing was conducted in ground effect (IGE) and out of ground effect (OGE) at wheel heights of 10, 20, 30, 50, 70, and 145 feet. At takeoff power, the standard-day OGE and IGE (10-foot) hover ceilings at maximum gross weights (47,000 pounds) were 6600 and 9050 feet, respectively. The hover ceiling on a 35°C day IGE was 4900 feet at maximum gross weight. Limited level flight performance was determined over a gross weight range from 26,070 to 29,990 pounds and a density altitude ( $H_D$ ) range of 5580 to 11,580 feet in the clean configuration (pod off). The airspeed for best endurance was nominally 65 knots true airspeed (KTAS). The never-exceed airspeed ( $V_{NE}$ ) (101 knots calibrated airspeed (KCAS)) was most suitable for long-range cruise; however, an approximate 33-percent increase in specific range could be achieved in the clean configuration by shutting down one engine after reaching cruise altitude. A level flight, unaccelerated airspeed envelope expansion was conducted in accordance with the AVSCOM test directive (ref 4, app A). Flights at airspeeds up to 125 KCAS were accomplished in level flight in the clean configuration.

### HOVER PERFORMANCE

9. Hover performance data were obtained both IGE and OGE, using the tethered hover method to obtain desired main rotor thrust. The aircraft hoist system cable length indicator was calibrated and used to determine precise wheel heights above the ground. A calibrated load cell to measure cable tension was installed between the aircraft hoist cable and a concrete deadman anchor. The load cell readout was transmitted to a nearby ground station. The test was conducted by stabilizing load cell readings incrementally from 1000 pounds to the maximum allowable, observing the aircraft limitations of the operator's manual (ref 6, app A). At each stable point, engine and aircraft data were recorded on magnetic tape and from cockpit instrumentation. Tests were conducted at 185 and 194 rpm at wheel heights of 10, 20, 30, 50, 70, and 145 feet. Results of the hovering performance tests are presented in figures 1 through 8, appendix E.

10. The summary of hover capability (fig. 1, app E) shows the standard-day OGE and IGE (10-foot) hover ceilings were 6600 and 9050 feet, respectively, at the maximum gross weight of 47,000 pounds. For a hot day (35°C), the OGE and IGE hover ceilings were 3000 and 4900 feet at the maximum gross weight. A comparison of test results and handbook data is presented in figure A.

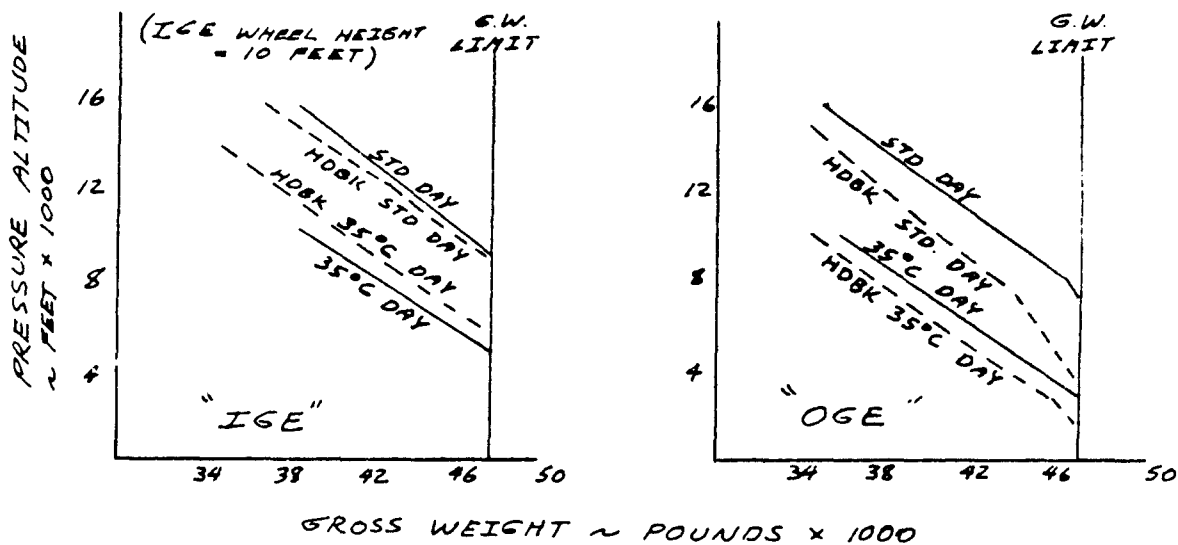


Figure A. Hover Performance Comparison.

#### LEVEL FLIGHT PERFORMANCE

11. Level flight performance tests were conducted to determine power required and fuel flow as a function of airspeed. In addition, specific range, long-range cruise speed ( $V_{CR}$ ), and endurance speed (speed at minimum power required for level flight) were determined. Data were obtained in stabilized level flight at incremental airspeeds from 25 KCAS to  $V_{NE}$ . A constant coefficient of weight ( $C_W$ ) was maintained by increasing altitude as fuel was consumed and keeping rpm constant. Tests were conducted under the conditions listed in table 1. The results of these tests are presented nondimensionally in figure 9, appendix E, and dimensionally in figures 10 through 13. Summaries of engine shp available and fuel flow versus shp are presented in figures 14 through 17. These summaries were derived from specification engine data (ref 9, app A).

12. Test results show that for all level flight test conditions, the maximum level flight airspeed of the CH-54B was limited by the current  $V_{NE}$  imposed by the operator's manual (ref 6, app A). This limit could easily have been exceeded with the power available, either dual engine below normal rated power, or single engine in the takeoff and 30-minute power range (80 to 100 percent torque). The endurance airspeed varied from 64 KTAS at the lowest  $C_W$  tested (0.006534 at a 26,070-pound gross weight and 5980 feet HP) to 67 KTAS at the highest  $C_W$  tested (0.008492 at a 28,600-pound gross weight and 11,430 feet HP). An endurance airspeed of 65 KTAS is recommended in the clean configuration.

13. The maximum specific range achieved was 0.0440 nautical air miles per pound of fuel at 11,430 feet H<sub>D</sub> and a 28,600-pound gross weight. Standard-day level flight range data for 5000 feet are summarized in figure 18, appendix E. Both single-engine and dual-engine specific range results are shown for comparison. Actual single-engine level flight performance was beyond the scope of these tests and was not performed; data were computed using dual-engine power required and the engine manufacturer's specification fuel flow. At a 30,000-pound gross weight and V<sub>NE</sub>, an estimated 33-percent increase in specific range could be achieved using only one engine during cruise. Single-engine operation from an altitude with adequate margin for air restart is feasible.

14. At density altitudes below 10,000 feet for all gross weights tested in the clean configuration, the operator's manual V<sub>NE</sub> (101 KCAS) prohibits operation at the normal cruise speed as defined by military specification MIL-C-5011A, "airspeed corresponding to the higher value of 99 percent maximum specific range." Test results show that for these conditions V<sub>NE</sub> occurs essentially at the peak of the specific range curve. Aircraft attitude, vibration level, and stability characteristics do not prohibit continuous flight at V<sub>NE</sub>; thus, 101 KCAS is the optimum airspeed for long-range cruise. Further testing should be accomplished with the EAPS installed to obtain level flight performance data for the operator's manual. Further testing should also be conducted to verify estimated single-engine performance.

#### AIRSPPEED ENVELOPE EXPANSION

15. A level flight, unaccelerated airspeed envelope expansion was conducted at 3000-, 6000- and 9000-foot density altitudes. Maximum airspeeds and gross weight were limited by the AVSCOM safety-of-flight release (ref 7, app A) and are summarized in figure 19, appendix E. The test was conducted by increasing airspeed incrementally to the maximum allowable while closely observing cockpit data and aircraft characteristics. Aircraft vibration, engine performance, and flight control position data were recorded on magnetic tape and are presented in figures 20 through 22, appendix E.

16. At the conditions tested, no difficulties were encountered in achieving the desired airspeeds due to power available, aircraft control, or vibration characteristics. Power required at the maximum airspeed tested was approximately 27 percent below normal rated power available. Longitudinal trimmed control positions indicated a 30-percent control margin remaining at the maximum airspeed tested. There were no significant vibration increases with higher airspeeds observed by the pilot or recorded on test instrumentation. Blade stall was not encountered at any of the test conditions and it appeared that higher level flight airspeeds could have been achieved. The aircraft attitude changed from 6 to 11 degrees, nose down, between the current handbook V<sub>NE</sub> (101 KCAS) to the maximum airspeed tested (125 KCAS). This increase was noticeable to the pilot; however, no discomfort was experienced. During these tests, aircraft stability and control characteristics, structural loads, and effects of the higher airspeeds on fatigue life were not evaluated. Further testing should be conducted to determine these factors.

17. While fuel flow increased from 2750 pounds per hour at the current VNE to 3600 pounds per hour at the expanded VNE (fig. 20, app E), specific range remained essentially unchanged. The level flight range characteristics at the expanded VNE are satisfactory.

#### PITOT-STATIC SYSTEM CALIBRATION

18. A pitot-static system calibration in level flight was conducted at 5540 feet HD using the trailing bomb method. The results of this test are presented in figure 23, appendix E. Position error of the ship's service system varied from +3 knots at 50 KCAS, through zero knots at 73 KCAS, to -4 knots at 100 KCAS. The position error characteristics of the ship's airspeed system agree favorably with current handbook data and are satisfactory.

19. When installed, the EAPS are in close proximity to the pitot tubes located above and slightly behind the cabin entrance doors; therefore, significant position error differences could be introduced. Further testing should be conducted to determine ship's service position error with the EAPS installed.

#### MISCELLANEOUS

20. One of the desirable features of the CH-54B helicopter was the load cell incorporated in the single-point hoist system to measure cable tension. This information was displayed by an indicator on the cockpit instrument panel as winch load. The cockpit indications were accurate and compared favorably with the calibrated test load cell used during the tethered hover performance tests. Aircraft gross weight could be quickly computed by adding the winch load to the basic weight of the aircraft and fuel on board. A similar device for all helicopters employed in sling load operations would greatly improve accuracy in the computation of aircraft gross weight.

## CONCLUSIONS

21. The following general conclusions were reached as a result of the CH-54B limited performance and airspeed envelope expansion tests:

- a. Hover performance exceeded current handbook data except for the IGE hot day (35°C) results (para 10).
- b. A level flight, unaccelerated airspeed envelope expansion from 101 KCAS to 125 KCAS was accomplished without encountering any unusual aircraft characteristics or limitations (paras 16 and 17).
- c. The cockpit winch load indicator enhanced sling load operations (para 20).
- d. No deficiencies or shortcomings were noted.

## **RECOMMENDATIONS**

22. Further testing should be conducted to determine the following:
  - a. Aircraft performance characteristics with the EAPS installed (para 14).
  - b. Structural loads and fatigue life of dynamic components at airspeeds greater than the current VNE (para 16).
  - c. The effects of higher airspeeds on the aircraft stability and control characteristics (para 16).
23. The current VNE (101 KCAS) should be used as the long-range cruise airspeed (para 14).
24. Sixty-five KTAS should be used as the maximum endurance airspeed (para 12).
25. A winch load indicator system should be installed in all cargo helicopters with a sling load capability (para 20).
26. Consideration should be given to shutting down one engine during cruise flight for better range performance (para 13).

## APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-R-F, 8 January 1971, subject: CH-54B Limited Airworthiness and Flight Characteristics Tests (A&FC).
2. Test Plan, USAASTA, Project No. 71-01, *Instrument Flight Rule Capability Evaluation, CH-54B Tarhe Helicopter*, July 1971.
3. Letter, AVSCOM, AMSAV-EF, 23 November 1971, subject: IFR Capability Evaluation, CH-54B Tarhe Helicopter.
4. Message, AVSCOM, AMSAV-EFT, 10-13, 16 October 1972, subject: CH-54B Limited Performance Tests.
5. Final Report, USAASTA, Project No. 71-01, *Instrument-Flight-Rules Capability Evaluation, CH-54B (Tarhe) Helicopter*, December 1972.
6. Technical Manual, TM 55-1520-217-10/2, *Operator's Manual, Army Model CH-54B Helicopters*, November 1969.
7. Letter, AVSCOM, AMSAV-EFT, 18 April 1972, subject: CH-54B Safety-of-Flight Release.
8. Flight Test Manual, Naval Air Test Center, FTM No. 102, *Helicopter Performance Testing*, 28 June 1968.
9. Specification, Pratt and Whitney Aircraft, No. A-2456, *Model T73-P-700 Engine*, 30 April 1970.



## **APPENDIX B. AIRCRAFT CHARACTERISTICS**

### **DIMENSION AND DESIGN DATA**

#### **Overall Dimensions**

Aircraft length, rotors turning	88 ft, 7 in.
Aircraft length, rotor blades removed	77 ft, 9 in.
Cockpit width	7 ft, 1 in.
Fuselage width	6 ft, 8 in.
Width, outside main landing gear	21 ft, 11 in.
Height, top of main rotor mast (landing gear struts compressed)	19 ft, 2 in.
Height, rotors turning (landing gear strut compressed)	25 ft, 5 in.
Clearance between main landing gear	17 ft, 7 in.
Tail rotor ground clearance at extreme position (landing gear struts compressed)	9 ft, 5 in.
Fuselage ground clearance between main landing gear (landing gear struts compressed)	9 ft, 4 in.

#### **Pod Dimensions**

Length, interior	27 ft, 5 in.
Length, exterior	28 ft, 1 in.
Width, interior, at floor	8 ft, 8 in.
Width, interior, at ceiling	8 ft, 10 in.
Width, exterior (pod only)	9 ft, 6 in.
Width, exterior (outside of wheels)	12 ft, 8 in.
Height, interior	6 ft, 6 in.
Height, exterior (wheels retracted)	7 ft, 8 in.

### Main Rotor Group

Rotor diameter	72 ft, 3 in.
Total blade area (6 blades)	384.6 ft <sup>2</sup>
Disc area	4098.2 ft <sup>2</sup>
Number of blades	6
Blade airfoil (root to tip)	NACA 0011 (modified)
Blade chord (root to tip)	26 in.
Blade twist (tip with respect to root)	10.65 deg counterclockwise
Solidity ratio	0.1150

### Tail Rotor Group

Rotor diameter	16 ft
Rotor blade area (4 blades)	33.12 ft <sup>2</sup>
Disc area	201.1 ft <sup>2</sup>
Number of blades	4
Blade airfoil (root to tip)	NACA 0012
Blade chord (root to tip)	15.4 in.
Blade twist (tip with respect to root)	8 deg counterclockwise
Solidity ratio	0.204

### Horizontal Stabilizer

Area	40 ft <sup>2</sup>
Airfoil (root to tip)	NACA 0012

Chord	56.5 in.
Span	8 ft. 6 in.
Aspect ratio	1.805

#### Main Transmission

Gear reduction stages:

Bevel	1
Ring and pinion	1
Planetary	2

Ratio:

Engine to main rotor shaft	48.609:1
Engine to tail rotor shaft	29.837:1

#### Intermediate Transmission

Gear reduction stages (bevel with an idler gear)	1
Drive angle change (input to output)	126 deg

#### Tail Rotor Transmission

Gear reduction stages (ring and pinion)	1
Drive angle change (input to output)	90 deg

#### Aircraft Limitations

Indicated airspeed	105 knots
Gross weight	47,000 lb
Load factor	2.0g

Center-of-gravity limits:

Forward

Below 30,000 lb FS 323

Above 42,000 lb, linear variation  
between 30,000 and 42,000 lb FS 328

Aft

Below 38,000 lb FS 349

Above 38,000 lb FS 346

Landing sink speed (at a 47,000-lb gross weight) 7.5 ft/sec

Hoist load 25,000 lb

Pod Limitations

Gross weight 20,000 lb

Center-of-gravity limits (gross weights refer to  
the combined aircraft and pod gross weights):

Forward

Below 43,680 lb FS 328.0

47,000 lb, linear variation between  
43,680 lb and 47,000 lb FS 331.0

Aft FS 346.0

Engines

Manufacturer Pratt and Whitney

Model T-73-P-700

Type Twin spool gas turbine  
(free turbine)

### Engine Limitations

#### Shaft horsepower:

30-minute limit	4800 shp
Maximum continuous	4430 shp
Compressor speed (maximum)	104.2 percent (16,700 rpm)

#### Free turbine speed:

Maximum (10,350 rpm)	114.4 percent
Maximum continuous operation	105.5 percent
Normal operating range (operate at 100 percent as much as possible)	99.4 to 105.5 percent

#### Power turbine inlet temperature:

During start	525°C
Ground idle	515°C
Continuous operation	675°C
30 minutes	720°C

### Transmission Limitations

#### Dual-engine operation:

10 seconds	8700 shp
30 minutes	7900 shp
Maximum continuous	6600 shp

#### Single-engine operation:

10 seconds	5600 shp
30 minutes	4800 shp
Maximum continuous	3300 shp

Rotor system limitations:

Normal operation (operate at 100 percent  
as much as possible)

100 to 104 percent  
(185 to 192 rpm)

Maximum (202 rpm)

110 percent

Minimum during autorotation (175 rpm)

95 percent

## APPENDIX C. DATA ANALYSIS METHODS

### INTRODUCTION

1. This appendix contains some of the data reduction and analysis methods used to evaluate the CH-54B helicopter. The topics discussed include:

- a. Shaft horsepower required.
- b. Shaft horsepower available.
- c. Hover performance.
- d. Level flight performance.
- e. Vibrations.

2. The following is a list of symbols used in the calculations:

<u>Parameter</u>	<u>Description</u>	<u>Engineering Unit</u>
$C_p$	Coefficient of power	--
$C_w$	Coefficient of weight	--
$\mu$	Advance ratio	--
$M_{tip}$	Advancing tip mach number	--
$\rho$	Air density	slug/ft <sup>3</sup>
$A$	Main rotor disc area	ft <sup>2</sup>
$\Omega$	Main rotor angular velocity	radians/sec
$R$	Main rotor radius	feet
$W$	Gross weight	pound
1.688	Conversion factor	ft/sec per knot
550	Conversion factor	(ft-lb/sec per SHP)
33,000	Conversion factor	(ft-lb/min per SHP)
$V_T$	True airspeed	knots

a	Speed of sound	ft/sec
Q	Engine output torque (No. 1 and No. 2)	percent
NR	Main rotor speed	RPM
GR	Gear ratio of the output shaft rotational speed to main rotor rotational speed	48.5437
GRT	Gear ratio of the tail rotor shaft rotational speed to the main rotor rotational speed	4.5825
Q <sub>tr</sub>	Main rotor torque	in.-lb
Q <sub>mr</sub>	Tail rotor torque	in.-lb
396,000	Tail rotor torque	in.-lb/min per SHP
W <sub>f</sub>	Specification fuel flow	lb/hr
KC	Temperature correction factor (T73-P-700 engine)	--
$\delta_{am}$	Ambient pressure ratio	--
$\theta_{am}$	Ambient temperature ratio	--
SHP <sub>S</sub>	Standard engine output shaft horsepower	SHP
$\rho_s$	Standard air density	slug/ft <sup>3</sup>
$\rho_t$	Test air density	slug/ft <sup>3</sup>
NAMPP	Nautical air miles per pound of fuel	knot/lb

### GENERAL

3. The helicopter performance test data were generalized through the use of nondimensional coefficients. The purpose was to accurately obtain performance at conditions not specifically tested. The following nondimensional coefficients were used to generalize test results obtained during the test program:



- a. Coefficient of power

$$C_p = \frac{SHP \times 550}{\rho A (\Omega R)^3} \quad (1)$$

- b. Coefficient of weight

$$C_w = \frac{W}{\rho A (\Omega R)^2} \quad (2)$$

- c. Advance ratio

$$\mu = \frac{1.6889 \times V_T}{\Omega R} \quad (3)$$

- d. Advancing tip mach number

$$M_{tip} = \frac{1.688 V_T + \Omega R}{a} \quad (4)$$

#### SHAFT HORSEPOWER REQUIRED

4. Engine output shp was determined from the calibrated engine torquemeters installed at the engine output shafts. The relationship between torquemeter output (percent) and engine output torque (Q (ft-lb)) is:

$$100 \text{ percent torque} = 2801 \text{ ft-lb}$$

Engine output shp was determined from the following equation:

$$SHP = \frac{2\pi \times GR \times NR \times (Q/100) \times 2801}{33,000} \quad (5)$$

5. Main rotor shp was measured using a calibrated strain gage torquemeter installed on the main rotor shaft. Main rotor shp was determined from the following relationship:

$$SHP_{mr} = \frac{2\pi \times NR \times C_{mr}}{396,000} \quad (6)$$

6. Tail rotor shp was measured using a calibrated strain gage torquemeter installed on the short shaft between the 45-degree gearbox at fuselage station (FS) 807 and the 90-degree gearbox at FS 870. No losses are assumed in the 90-degree gearbox. Tail rotor shp was determined from the following relationship:

$$\text{SHP}_{\text{tr}} = \frac{2\pi \times \text{NR} \times Q_{\text{tr}} \times \text{GRT}}{396,000} \quad (7)$$

#### SHAFT HORSEPOWER AVAILABLE

7. Shaft horsepower available for a specification engine was obtained from Pratt and Whitney Specification No. A2456. Zero inlet losses, zero exhaust losses, no horsepower extraction, anti-ice off, and no bleed air losses were assumed.

#### SPECIFICATION FUEL FLOW

8. Specification fuel flow was obtained from Pratt and Whitney Specification No. A2456. Specification fuel flow can be determined from figure 17, appendix E, and the following relationships:

$$\begin{aligned} \text{Corrected shaft horsepower} &= \text{SHP}_s / \left( \sqrt{\theta_{\text{am}}} \delta_{\text{am}} \right) \\ W_f &= (\text{corrected fuel flow}) \times \delta_{\text{am}} / \text{KC} \end{aligned} \quad (8)$$

#### HOVERING PERFORMANCE

9. Equations 1 and 2 were used to define hover capability. Summary hovering performance was calculated from nondimensional hovering curves by dimensionalizing the curves at selected ambient conditions.

#### LEVEL FLIGHT PERFORMANCE

10. Level flight performance was defined by measuring the engine output shp required to maintain level flight throughout the airspeed range tested. The results of each level flight were presented in terms of shp required, advancing tip mach number, and specific range versus true airspeed.

11. Test day level flight power was corrected to standard day conditions by assuming that the test day dimensionless parameters  $CP_t$ ,  $CW_t$ , and  $\mu_t$  are independent of atmospheric conditions. Consequently, the standard day dimensionless parameters,  $CP_s$ ,  $CW$ , and  $\mu_s$  are identical to the test day dimensionless parameters. From the definition of CP (equation 1), the following relationship can be derived:

$$SHP_s = SHP_t \times \frac{\rho_s}{\rho_t} \quad (9)$$

The relationship shown by equation 9 then defines the standard day power required for each test point.

12. Specific range was calculated using the nondimensional level flight performance curve and the specification fuel flow characteristics:

$$\text{Specific range (NAMPP)} = \frac{VT}{W_f} \quad (10)$$

### VIBRATIONS

13. Vibration data were recorded during the VNE expansion. The data were reduced on a Spectral Dynamics Model S01A spectrum analyzer. The data were analyzed over the range of zero to 500 Hz and zero g to 1g. The significant peak g amplitudes were presented as a function of cycles per rotor revolution and calibrated airspeed.

## APPENDIX D. TEST INSTRUMENTATION

1. Flight test instrumentation was installed in the test helicopter prior to the start of this evaluation. All instruments were calibrated and maintained by USAASTA prior to initiation of flight testing. Performance data were hand recorded from the instrument panel and recorded on magnetic tape using pulse code modulation (PCM). Vibration data were recorded on magnetic tape using frequency modulation (FM).

### Instrument Panel (Pilot/Copilot)

Airspeed (boom)  
Airspeed (ship's system)  
Outside air temperature  
Rotor speed  
Engine pressure ratio (No. 1 and No. 2)  
Pressure altitude (boom)  
Pressure altitude (ship's system)  
Fuel-used totalizer (No. 1 and No. 2)  
Wheel height (calibrated winch cable length)  
Time

### Magnetic Tape (PCM)

Time	Longitudinal AFCS position
Pilot event	Main rotor speed
Engineer event	Engine output torque (Q No. 1 and No. 2)
Pressure altitude (boom)	Main rotor torque
Angle of sideslip	Tail rotor torque
Pitch attitude	Fuel flow rate ( $W_f$ No. 1 and No. 2)
Longitudinal control position	Fuel-used totalizer

### Magnetic Tape (FM)

A celerometer location:

Pilot seat triaxial (FS 130, BL 21, WL 130)  
Center of gravity triaxial (FS 320, BL 30, WL 161)

2. The following additional information was ground recorded for hover performance:

Pressure altitude  
Ambient temperature  
Wind velocity  
Cable tension

## APPENDIX E. TEST DATA

### INDEX

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FIGURE 1 SUMMARY HOVERING PERFORMANCE  
CH-54B USA S/N 18463

T73-P-700 ENGINES (2)  
TAKE OFF AND 30 MINUTE LIMIT POWER

NOTES

1. POWER AVAILABLE BASED ON FIGURE 14
2. HOVER DATA DERIVED FROM FIGURES 3 AND 8
3. ROTOR SPEED = 185 RPM
4. WIND LESS THAN 4 KNOTS

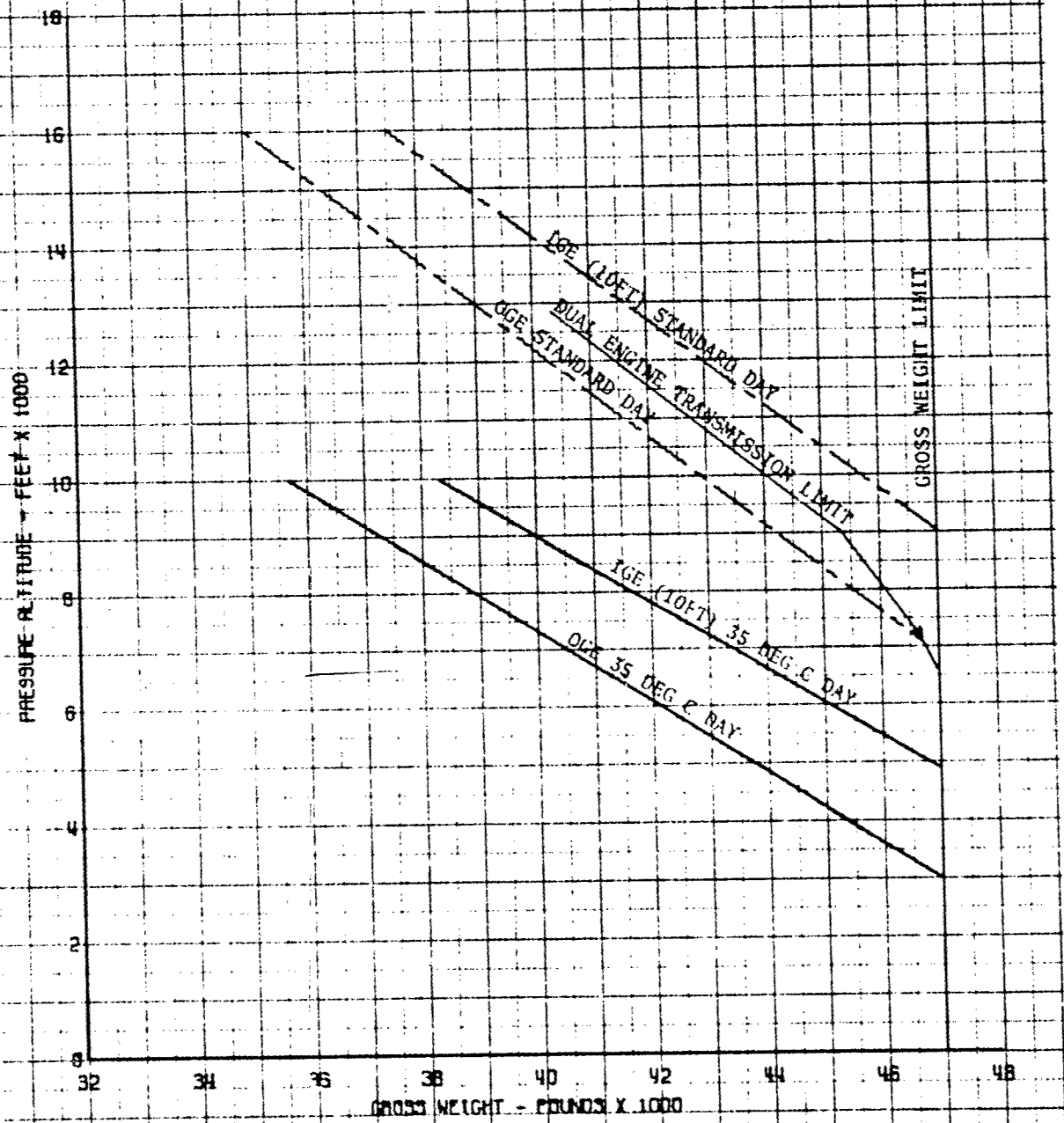


FIGURE 2 NON-DIMENSIONAL HOVERING PERFORMANCE SUMMARY  
CH-54B USA S/N 18463

- NOTES  
1. CURVES DERIVED FROM FIGURE 3 THRU FIGURE 8  
2. WHEEL HEIGHT MEASURED FROM THE BOTTOM  
OF THE REAR WHEELS  
3. WIND LESS THAN 4 KNOTS  
4. 185 RPM AND 183 RPM

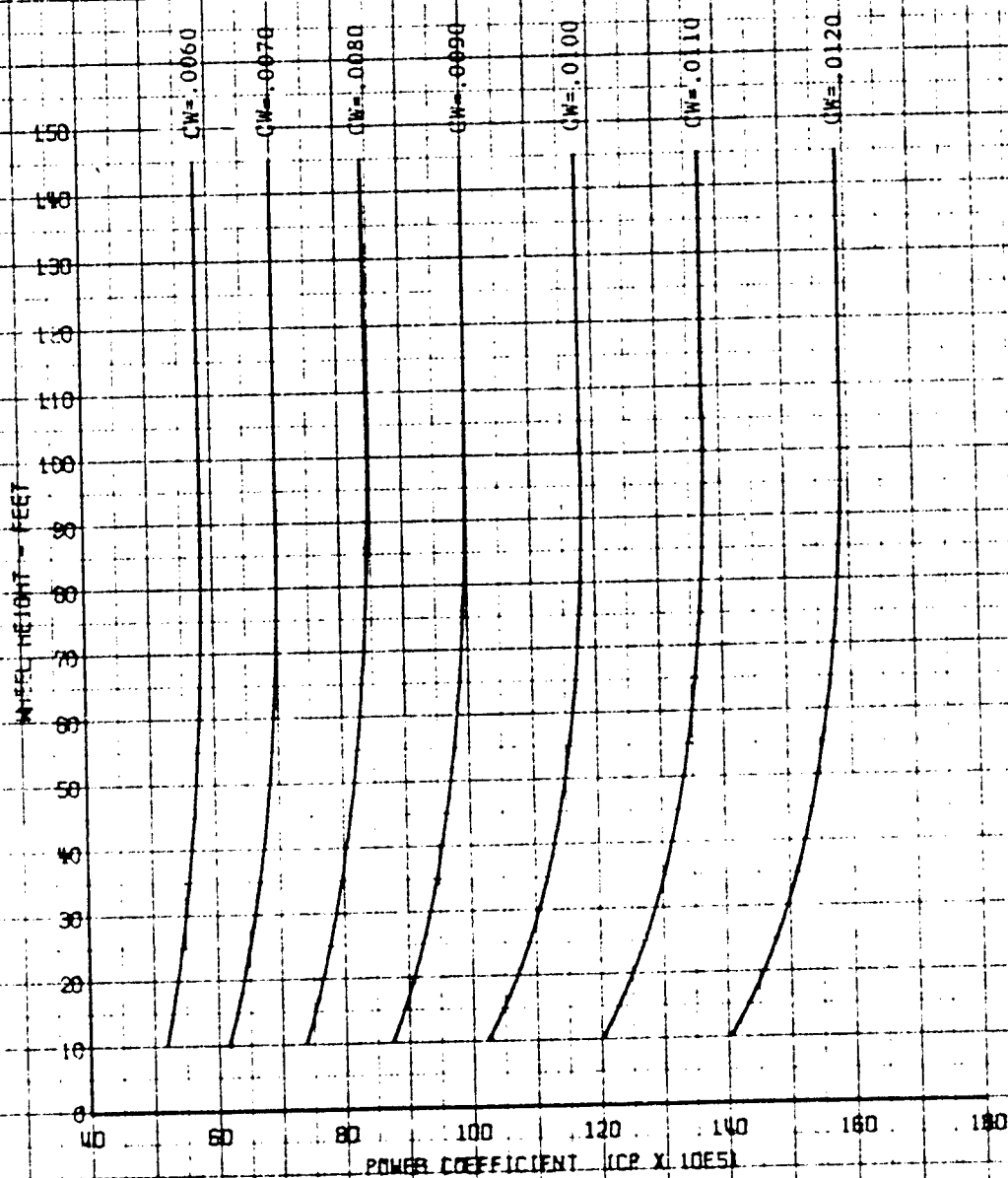


FIGURE 3 NON-DIMENSIONAL HOVERING PERFORMANCE  
CH-54B USA S/N 18463

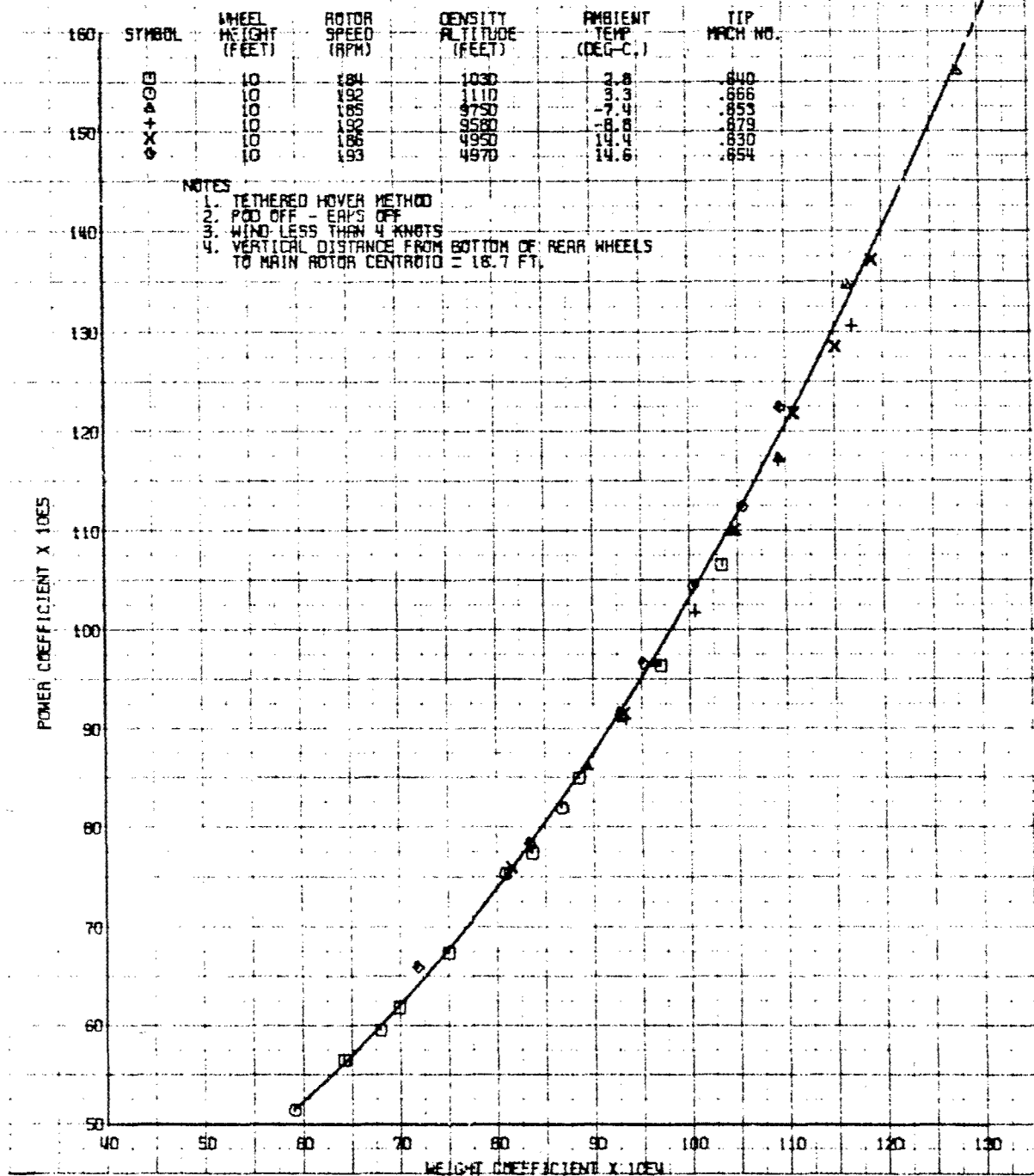




FIGURE 4 NON-DIMENSIONAL HOVERING PERFORMANCE  
CH-54B USA S/N 18463

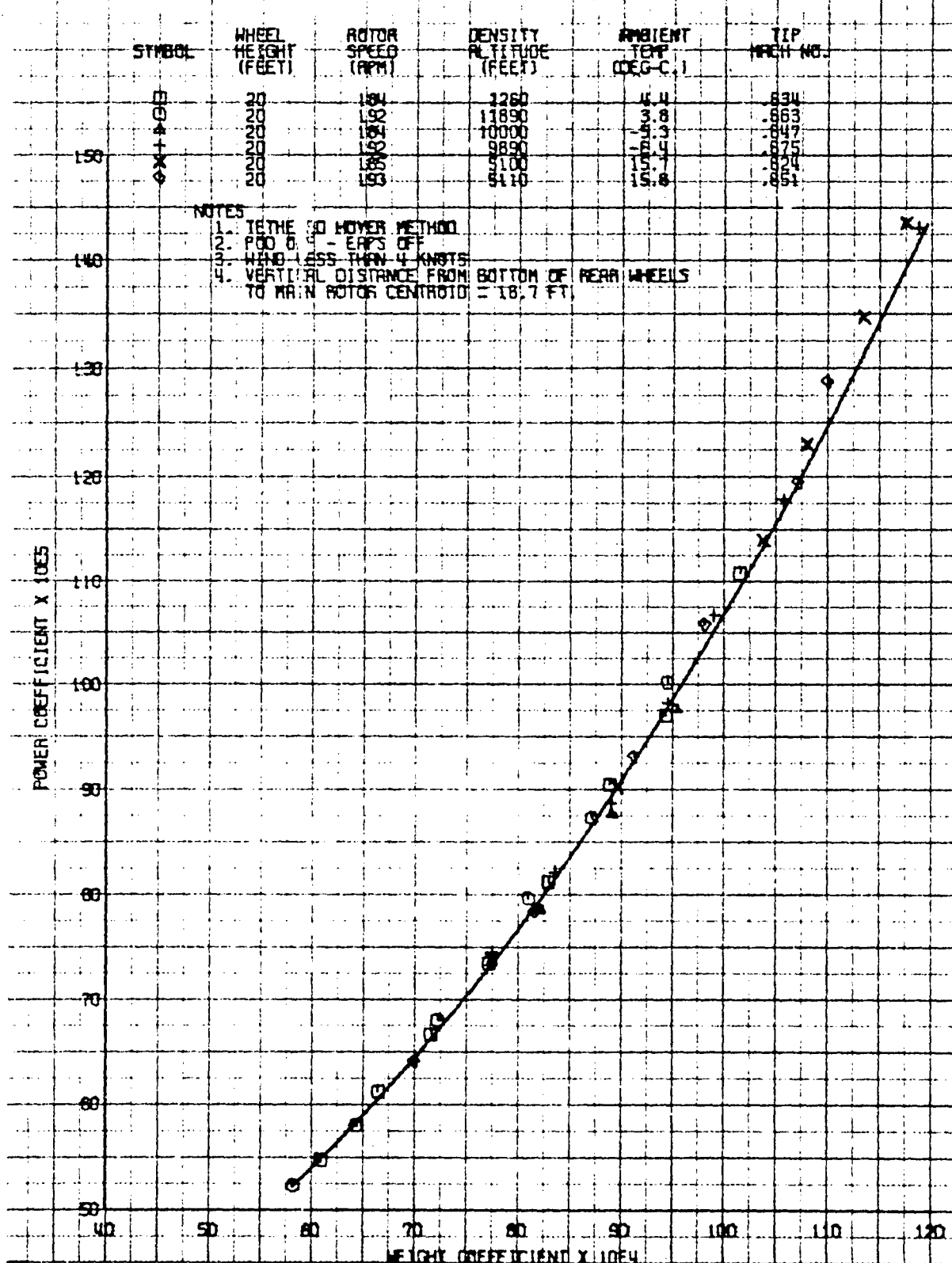


FIGURE 5 NON-DIMENSIONAL HOVERING PERFORMANCE  
CH-54B USA S/N 18463

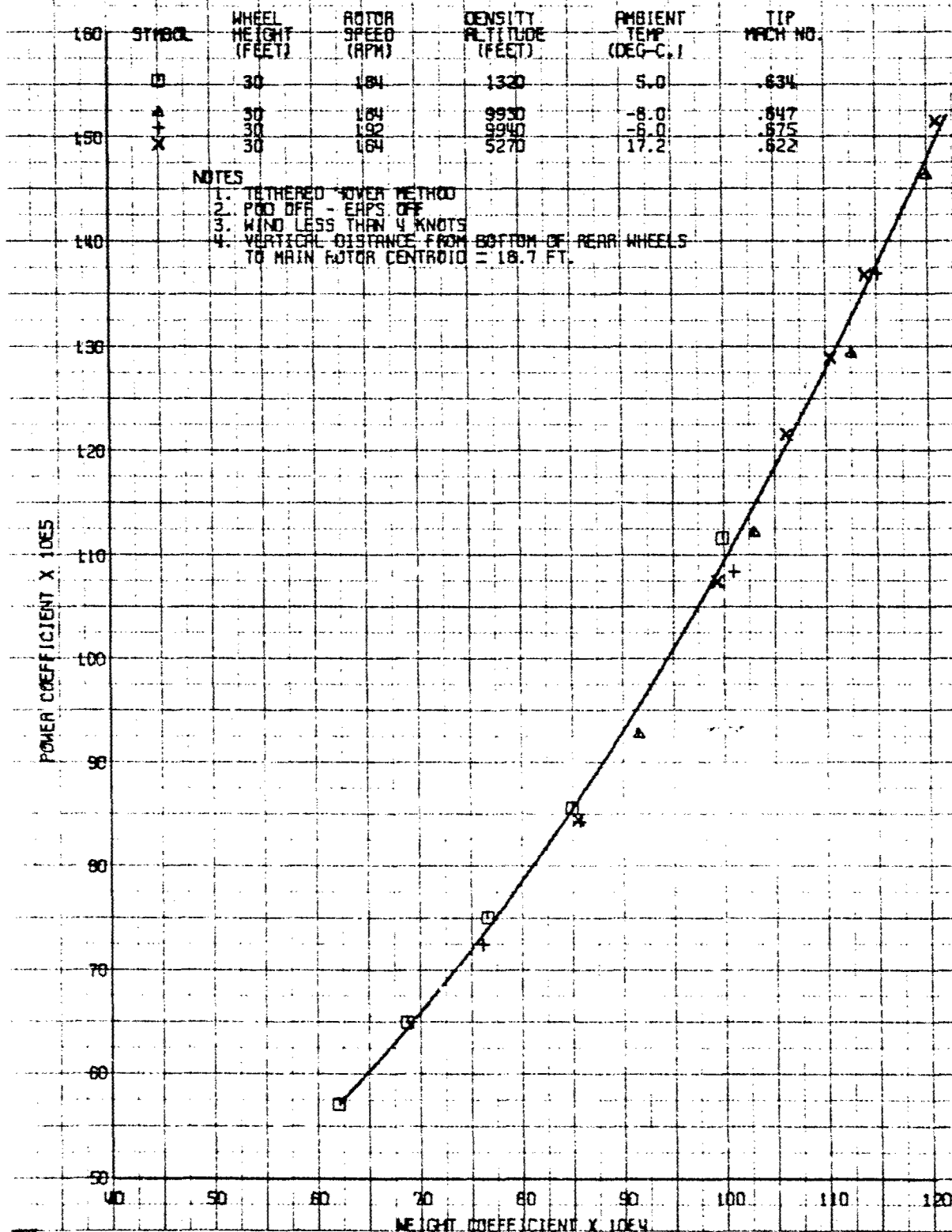


FIGURE 6 NON-DIMENSIONAL HOVERING PERFORMANCE  
CH-54B USA S/N 18463

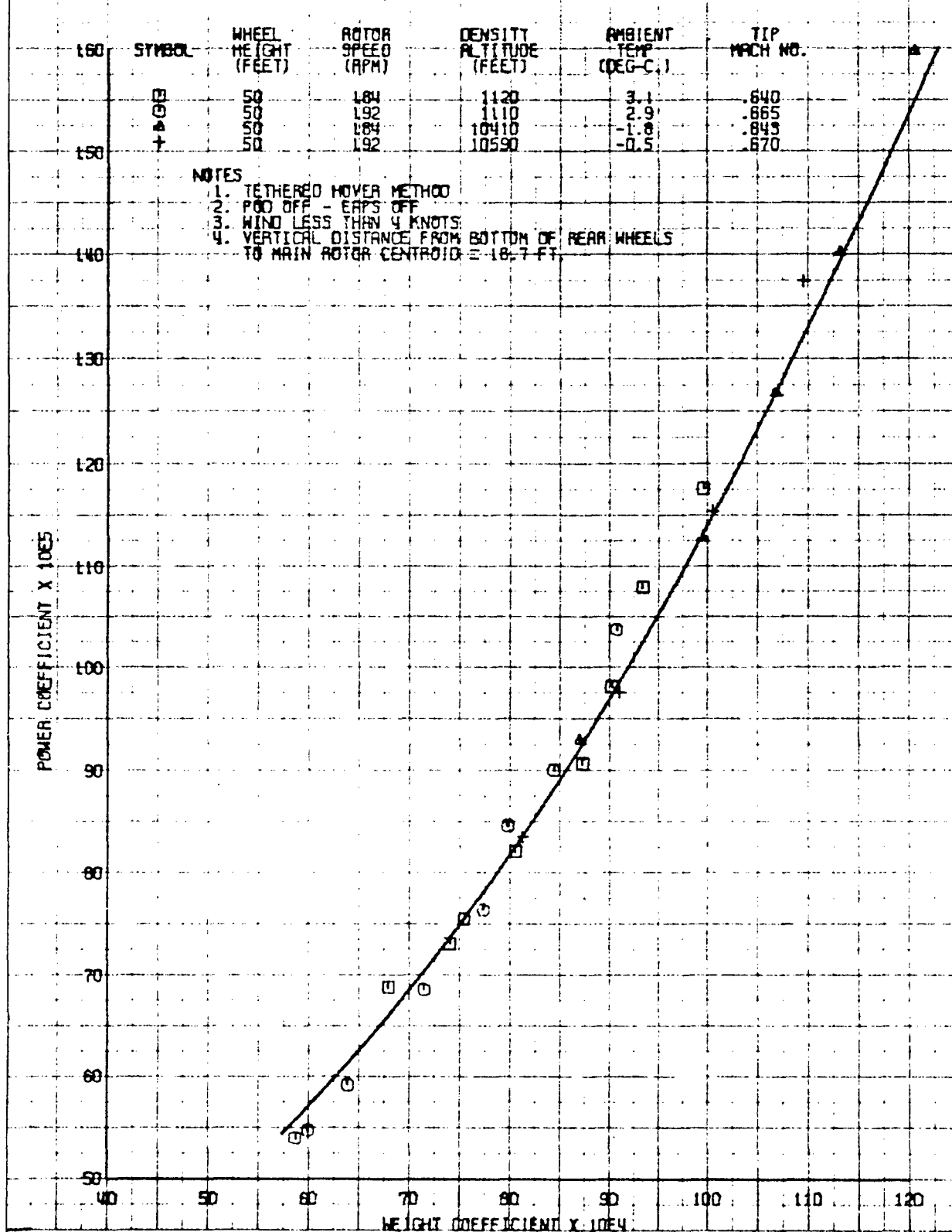


FIGURE 7 NON-DIMENSIONAL HOVERING PERFORMANCE  
CH-53B USA S/N 18463

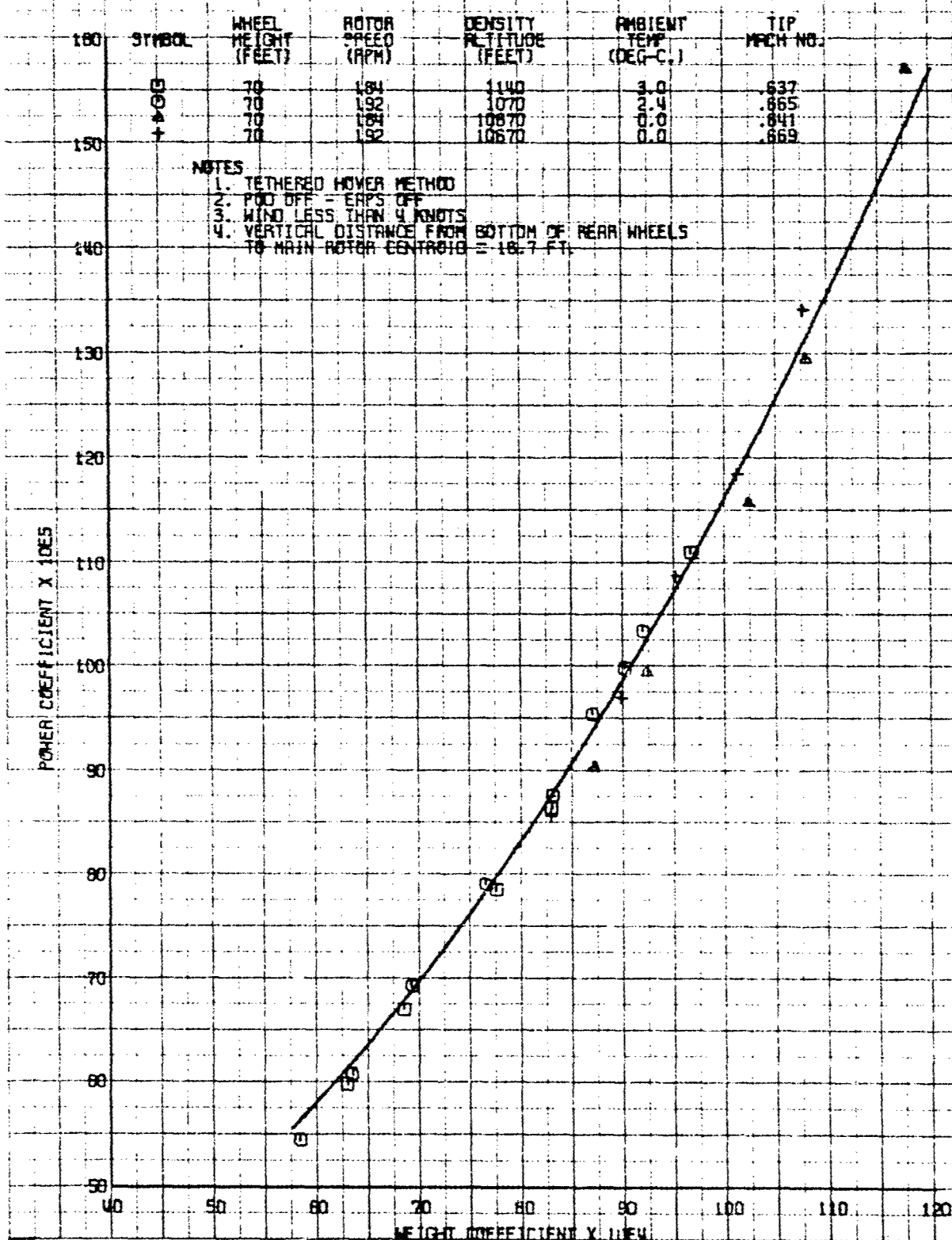


FIGURE B NON-DIMENSIONAL HOVERING PERFORMANCE  
CH-54B USA S/N 18463

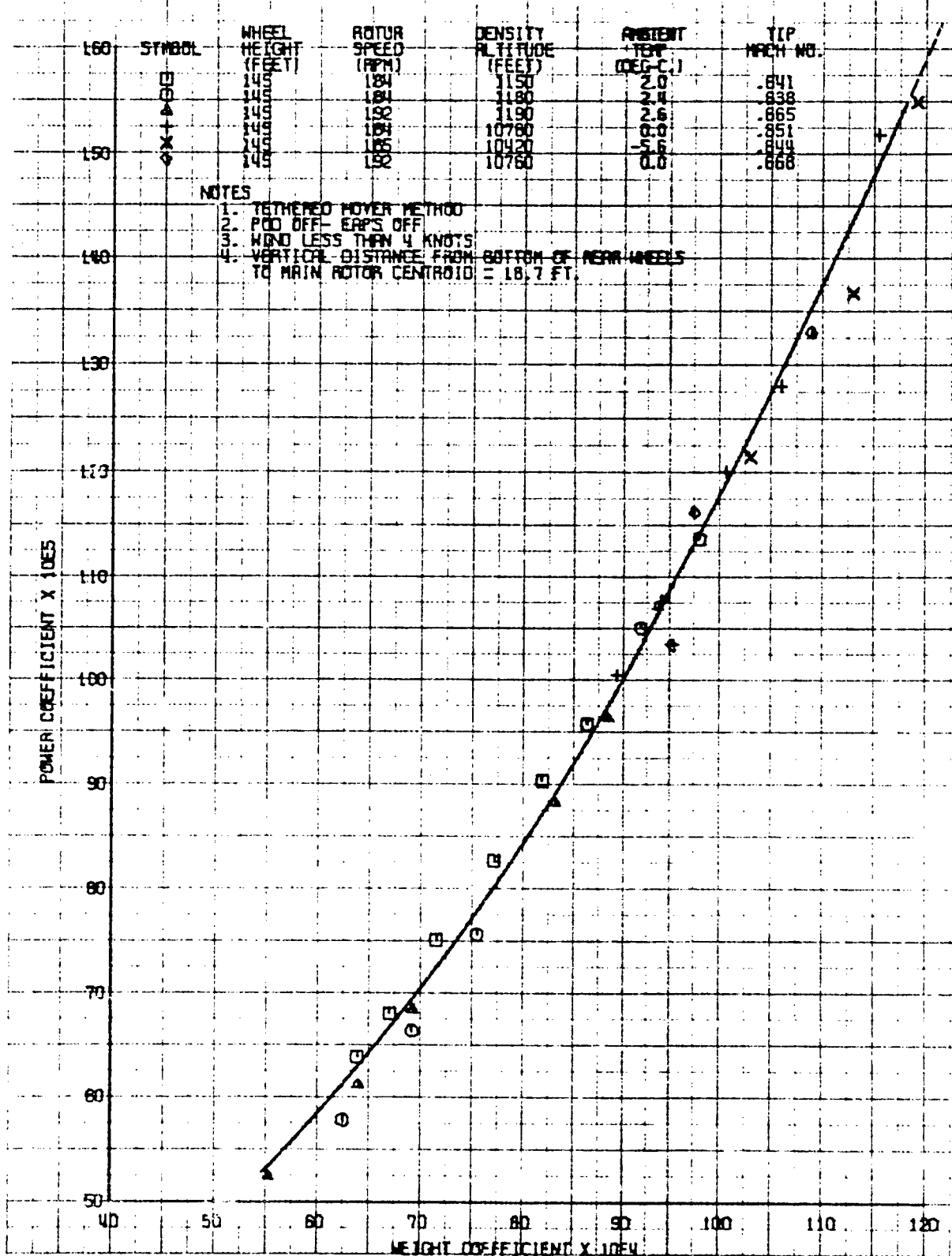


FIGURE 9 NON - DIMENSIONAL LEVEL FLIGHT PERFORMANCE  
CH-SUB USA S/N 18463

NOTES

1. AVERAGE MOTOR SPEED - 185 RPM
2. AVG CG LOCATION - 336.0 IN (M10)
3. CONFIGURATION - POD OFF - EAPS OFF
4. CURVES DERIVED FROM FIGURES 10 THRU 13

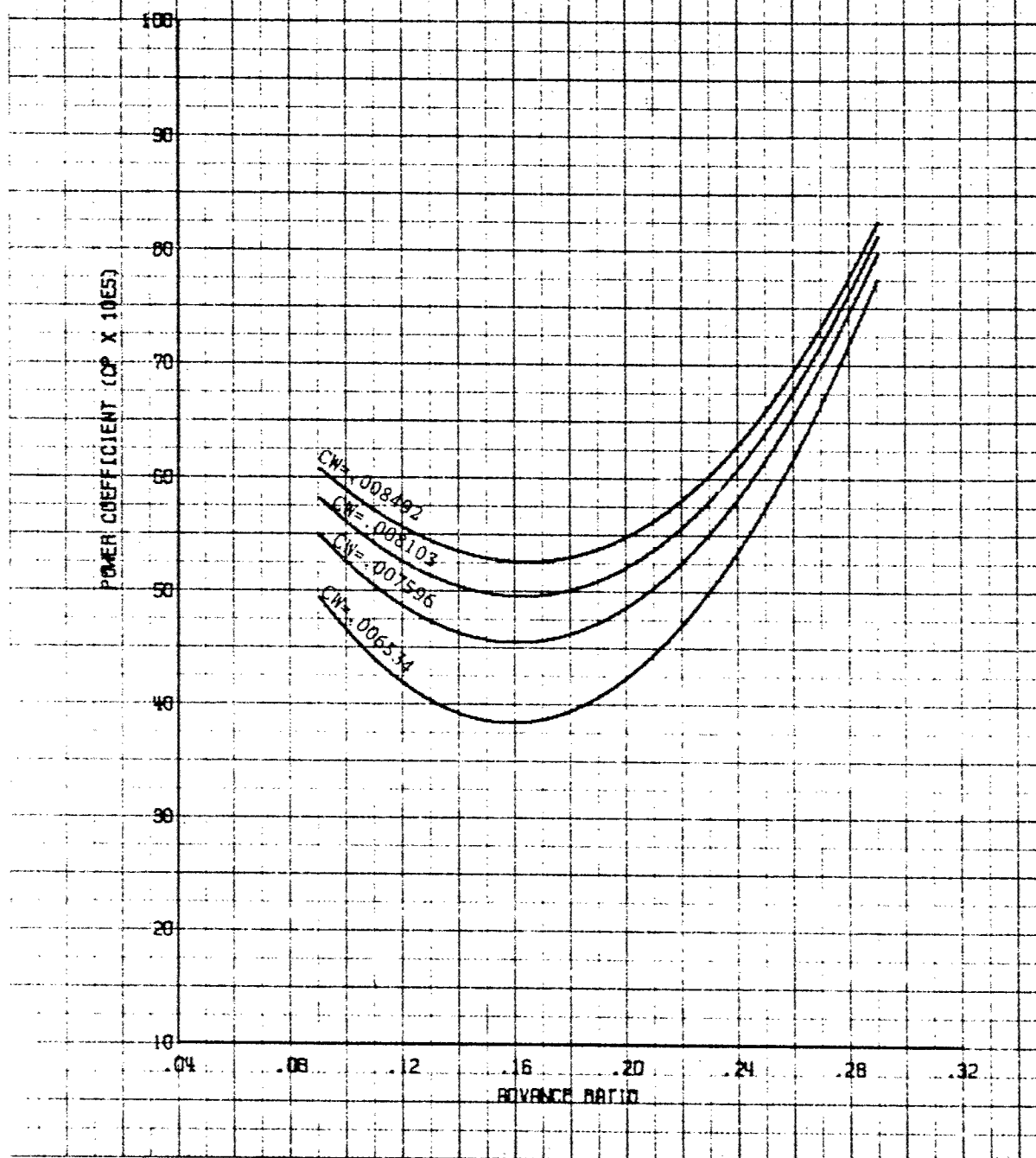


FIGURE 10 LEVEL FLIGHT PERFORMANCE  
CH-54B USA S/N 18469  
T73-P-700 ENGINES (2)

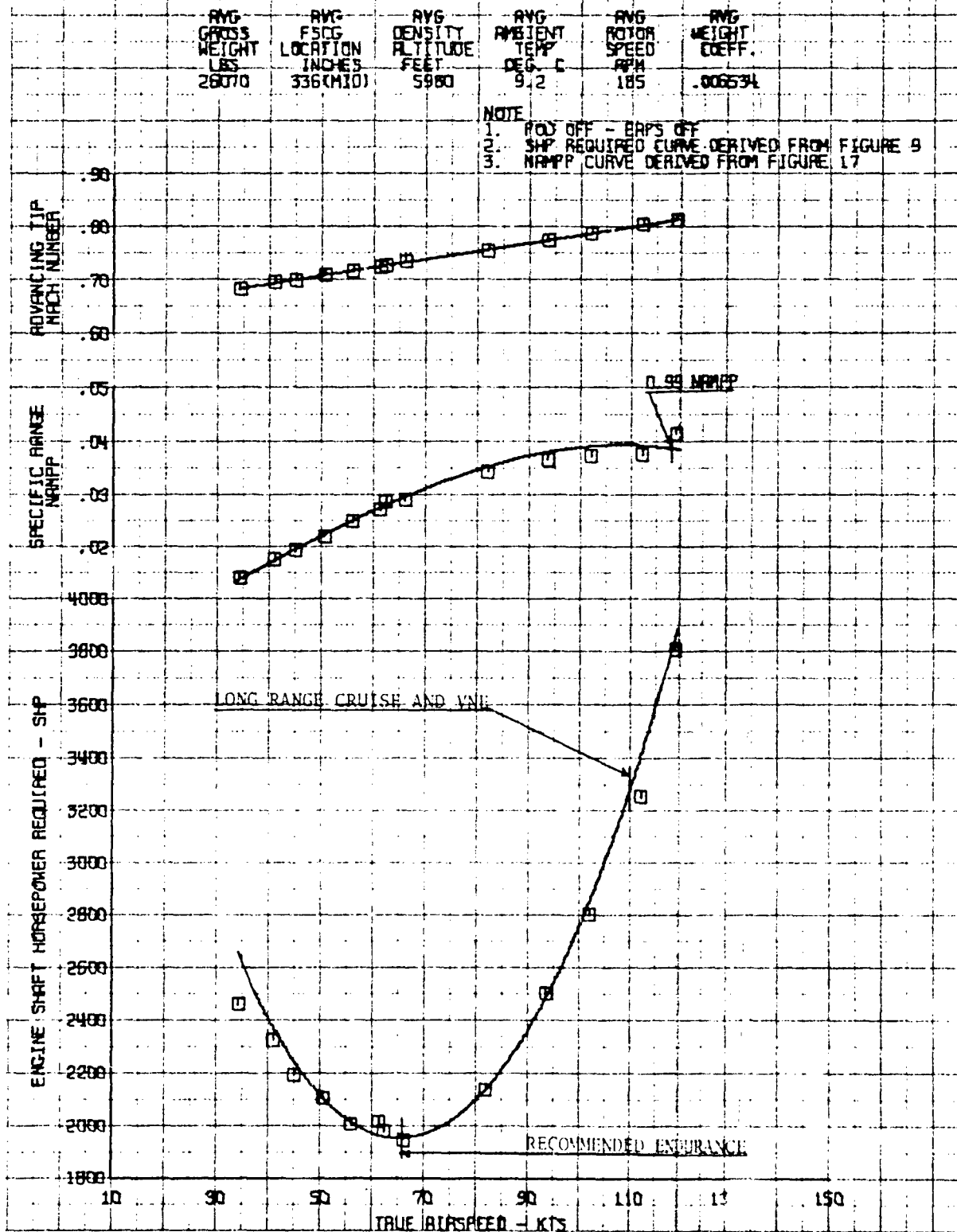


FIGURE 11 LEVEL FLIGHT PERFORMANCE  
 LH-54B USA 9/N 18643  
 T73-P-700 ENGINES (2)

AVG GROSS WEIGHT LBS	AVG FSCG LOCATION INCHES	AVG DENSITY ALTITUDE FEET	AVG AMBIENT TEMP DEG. C	AVG ROTOR SPEED RPM	AVG WEIGHT COEFF.
27580	336 (M10)	9040	-5.6	185	.007596

NOTE  
 1. POD OFF - EAPS OFF  
 2. SHP REQUIRED CURVE DERIVED FROM FIGURE 9  
 3. NAMPP CURVE DERIVED FROM FIGURE 17

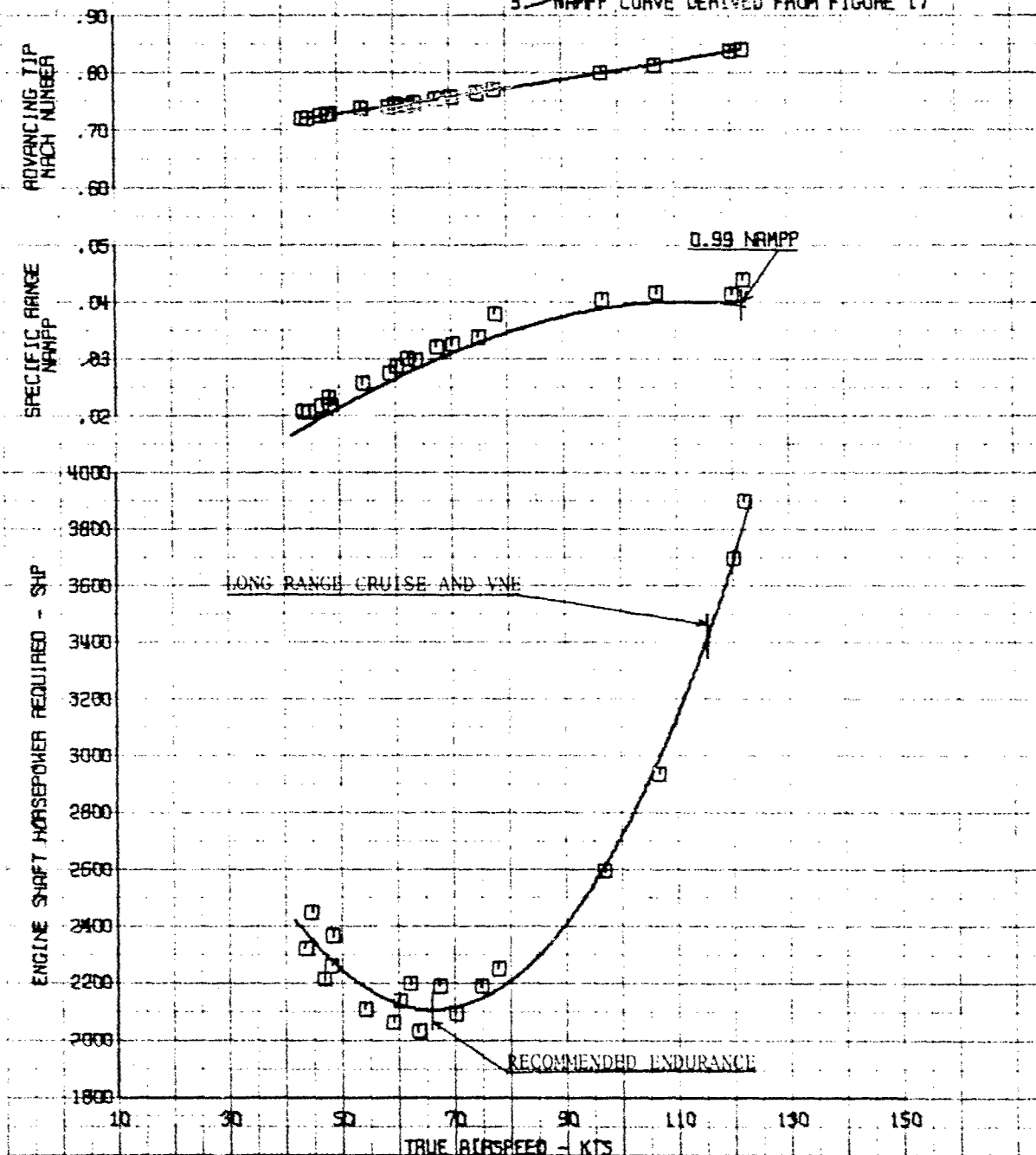




FIGURE 12 LEVEL FLIGHT PERFORMANCE  
CH-54B USA S/N 18643  
T73-F-700 ENGINES (2)

AVG GROSS WEIGHT LBS	AVG FSCG LOCATION INCHES	AVG DENSITY ALTITUDE FEET	AVG AMBIENT TEMP DEG. C	AVG ROTOR SPEED RPM	AVG WEIGHT COEFF.
29890	336 (M10)	8520	-4.6	185	.008103

- NOTE
1. POD OFF - ERPS OFF
  2. SHP REQUIRED CURVE DERIVED FROM FIGURE 9
  3. NAMPP CURVE DERIVED FROM FIGURE 17

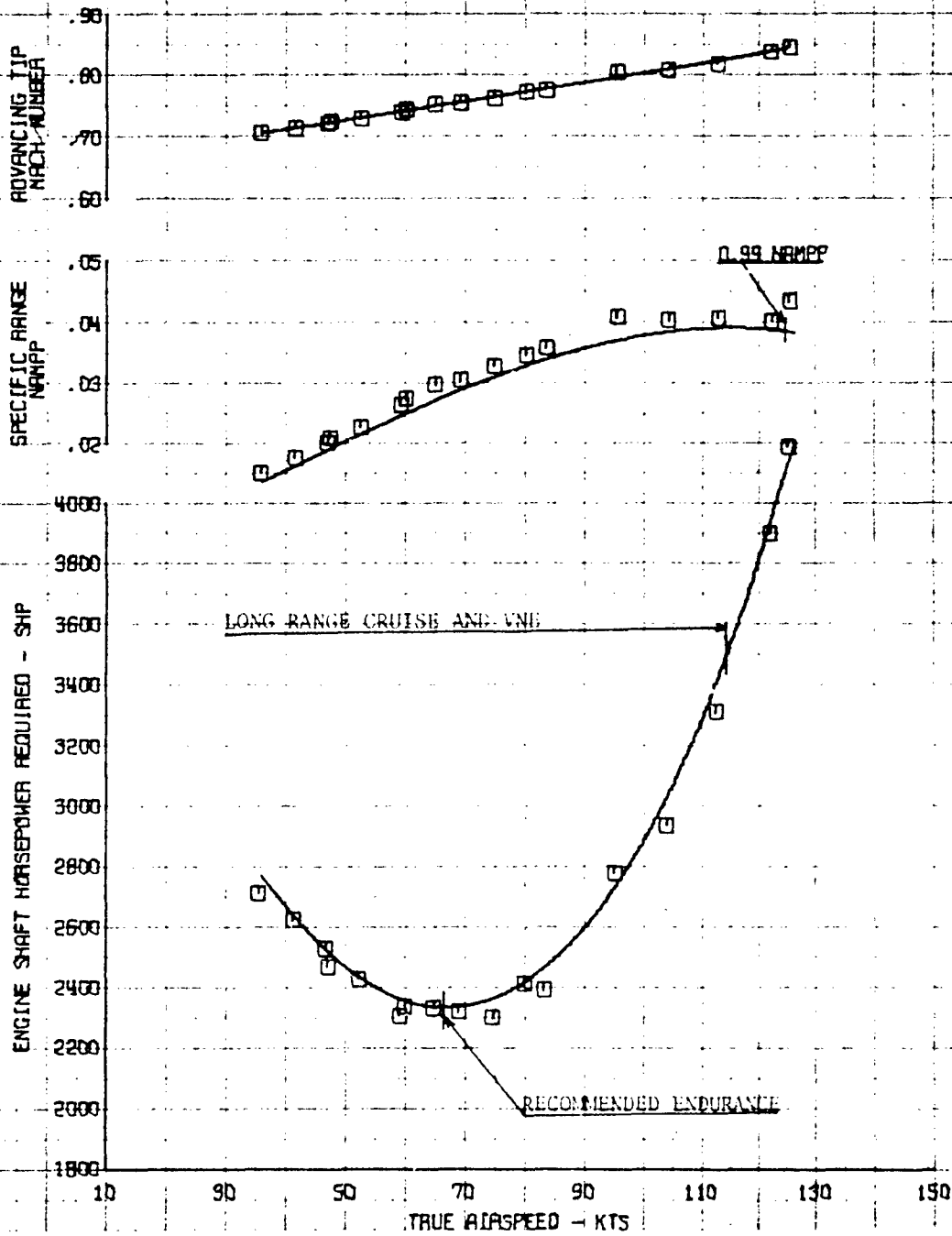


FIGURE 13 LEVEL FLIGHT PERFORMANCE  
CH-54B USA S/N 18643

T73-F-700 ENGINES (2)

AVG GROSS WEIGHT LBS	AVG FSCG LOCATION INCHES	AVG DENSITY ALTITUDE FEET	AVG AMBIENT TEMP DEG. C	AVG ROTOR SPEED RPM	AVG WEIGHT COEFF.
28600	336 (M10)	11430	4.6	185	.008492

NOTE

1. PFD OFF - HAPS OFF
2. SHP REQUIRED CURVE DERIVED FROM FIGURE 9
3. NAMPP CURVE DERIVED FROM FIGURE 17

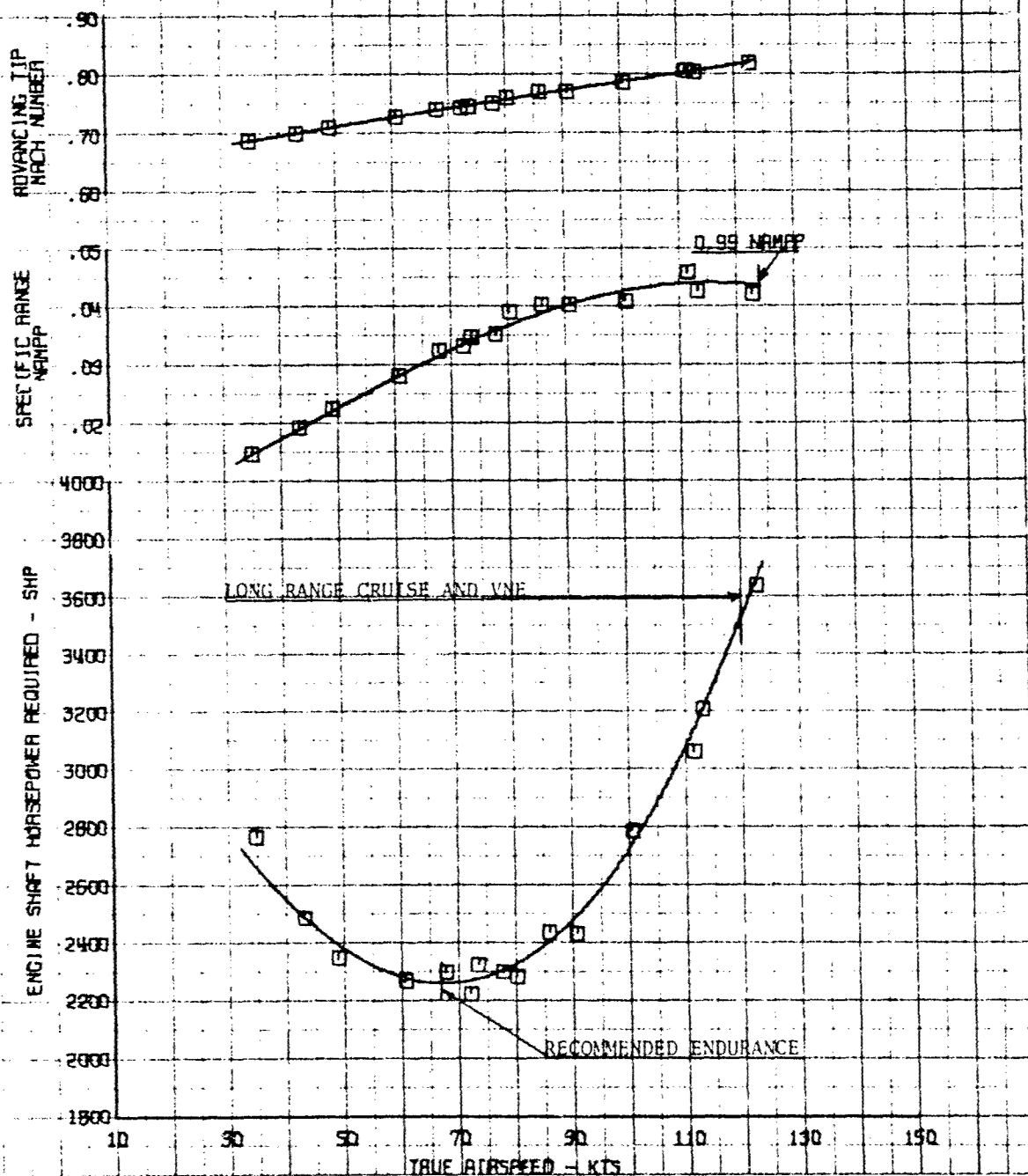
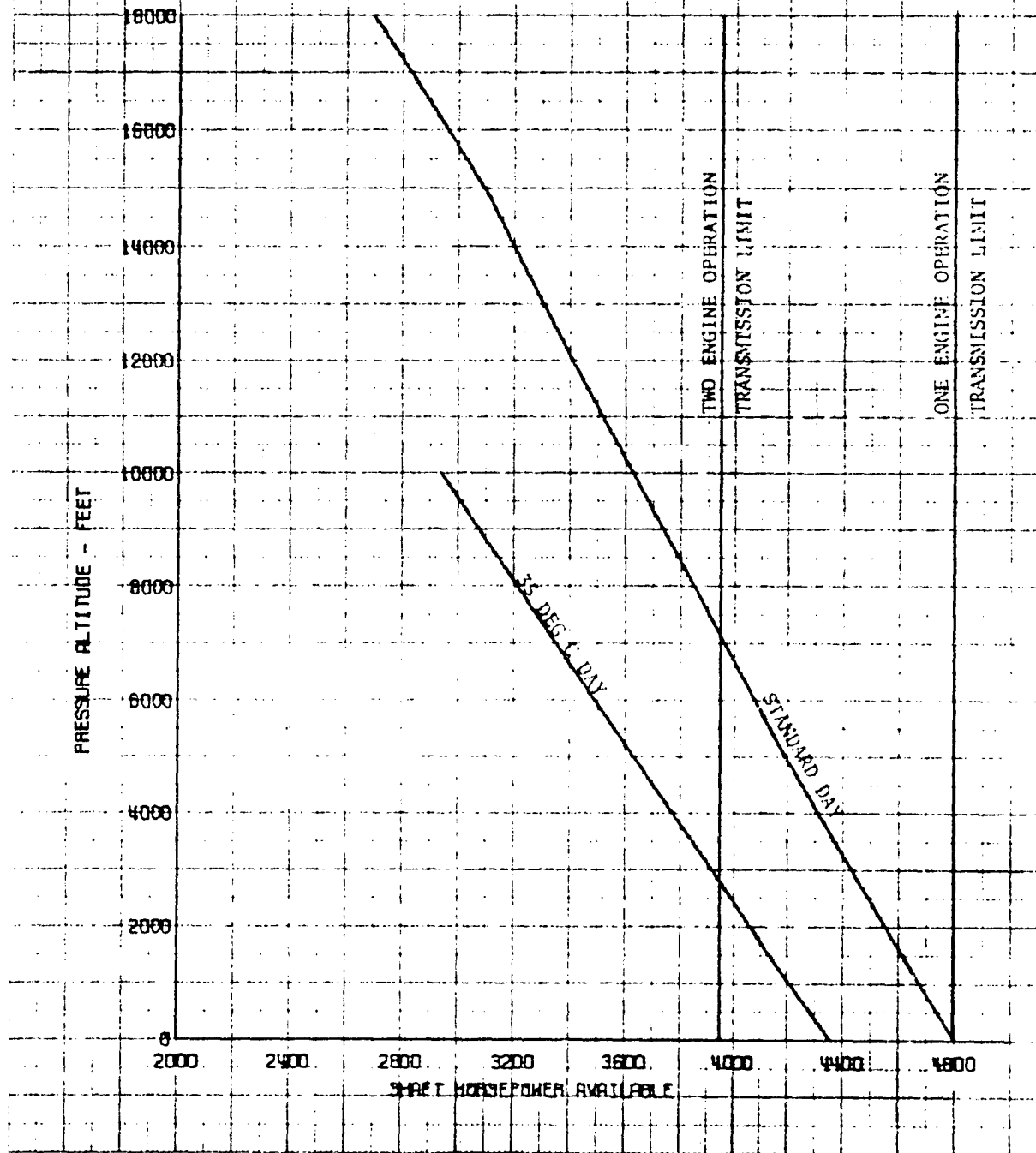


FIGURE 14 SHAFT HORSEPOWER AVAILABLE PER ENGINE  
TAKE OFF AND 30 MINUTE RATINGS

F73-P-700 ENGINE  
ENGINE SPEED (N2) = 9000 RPM

NOTES

1. STATIC CONDITIONS
2. ANTI-ICE OFF
3. ZERO INLET LOSSES
4. ZERO EXHAUST PRESSURE LOSS
5. NO HORSEPOWER EXTRACTION
6. BASED ON PRATT AND WHITNEY SPECIFICATION NO. A-2456



**FIGURE 15 SHAFT HORSEPOWER AVAILABLE PER ENGINE  
MAXIMUM CONTINUOUS RATING**

T73-P-100 ENGINE  
ENGINE SPEED (N21) = 9000 RPM

**NOTES**

1. STATIC CONDITIONS
2. ANTI-ICE OFF
3. ZERO INLET LOSSES
4. ZERO EXHAUST PRESSURE LOSS
5. NO HORSEPOWER EXTRACTION
6. BASED ON PRATT AND WHITNEY SPECIFICATION NO. P-2456

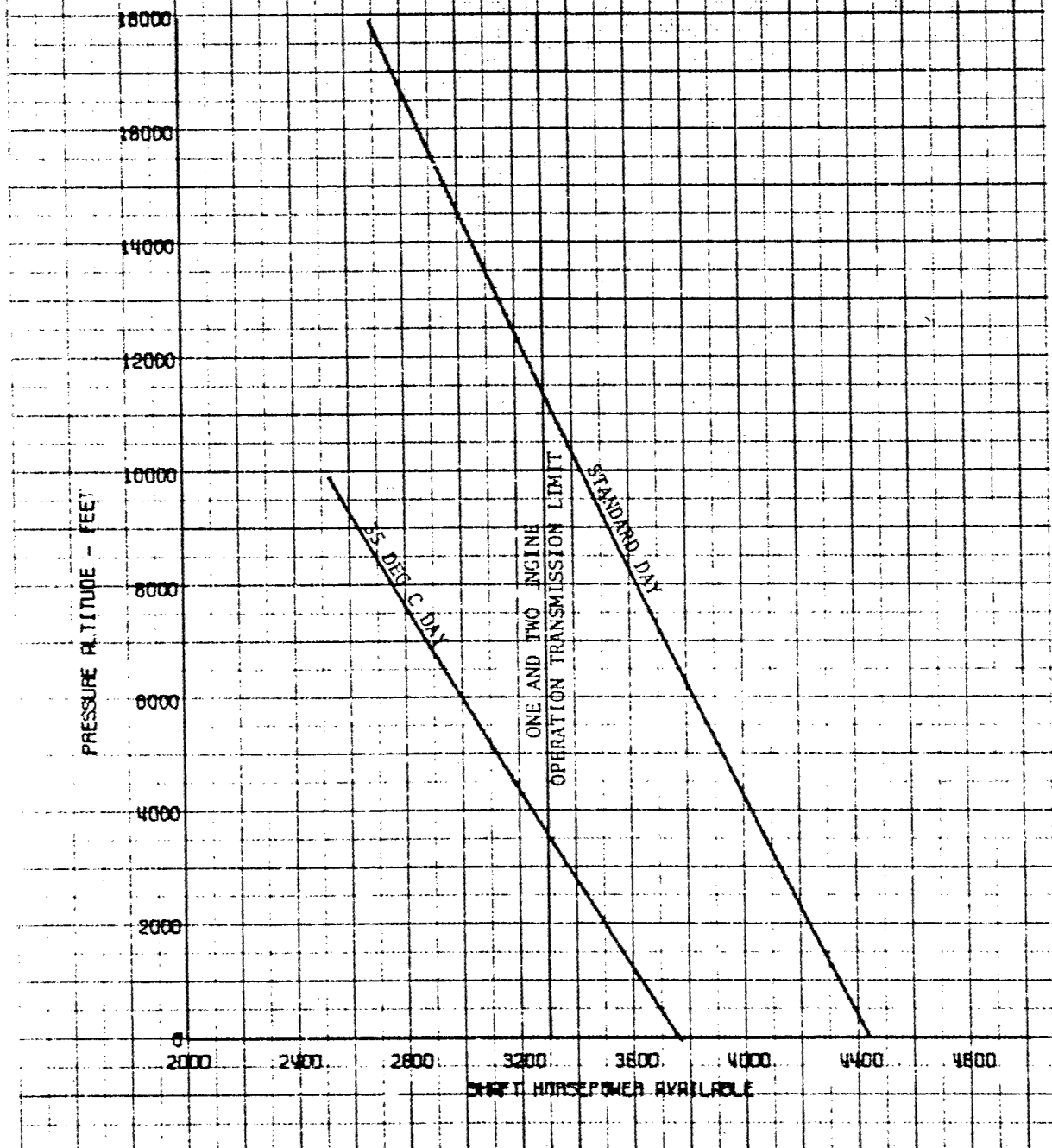


FIGURE 16 SHAFT HORSEPOWER AVAILABLE WITH RAM EFFECTS  
T73-P-700 ENGINE

ENGINE SPEED (N2) - 9000 RPM

STANDARD DAY

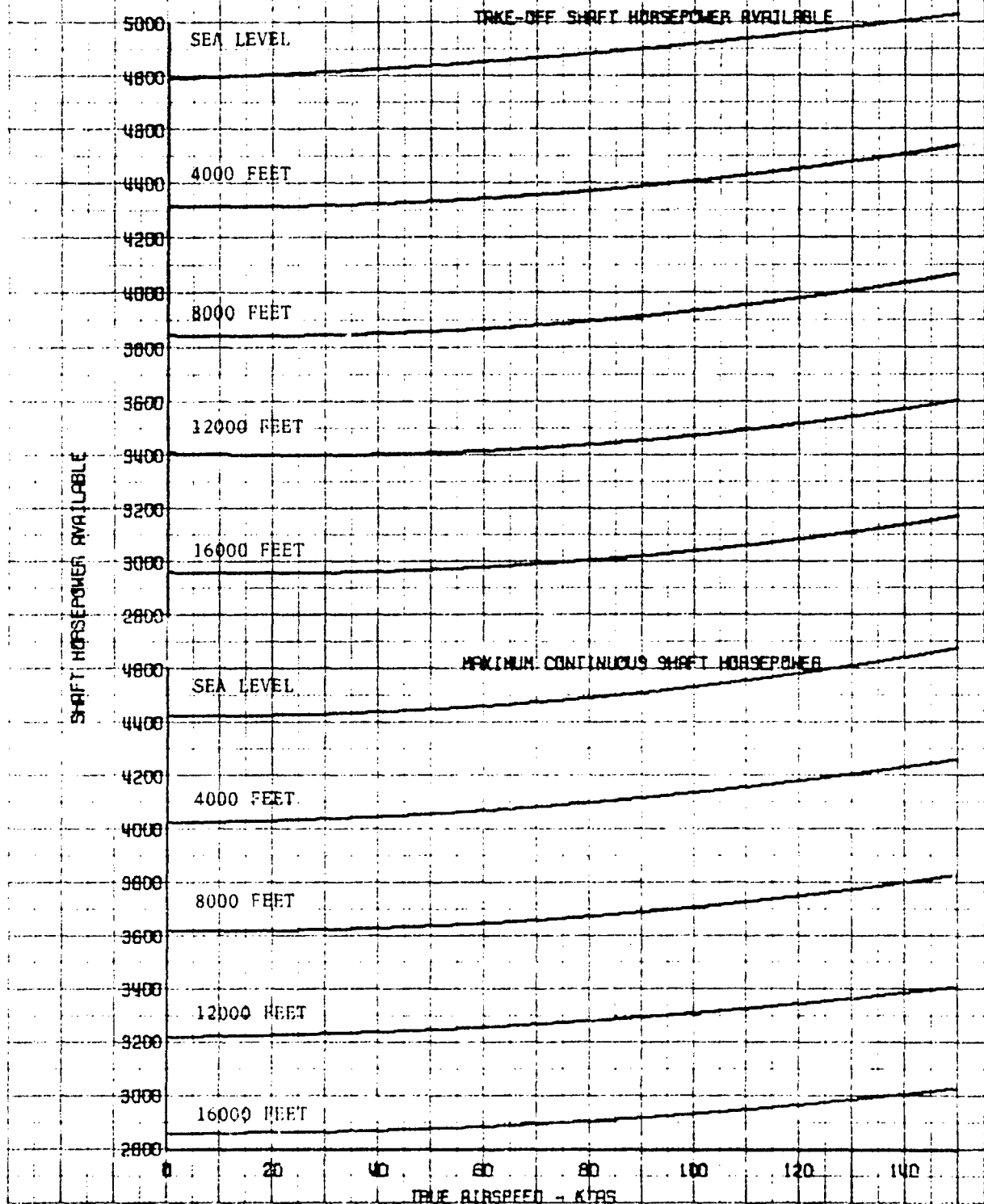


FIGURE 17. SPECIFICATION FUEL FLOW

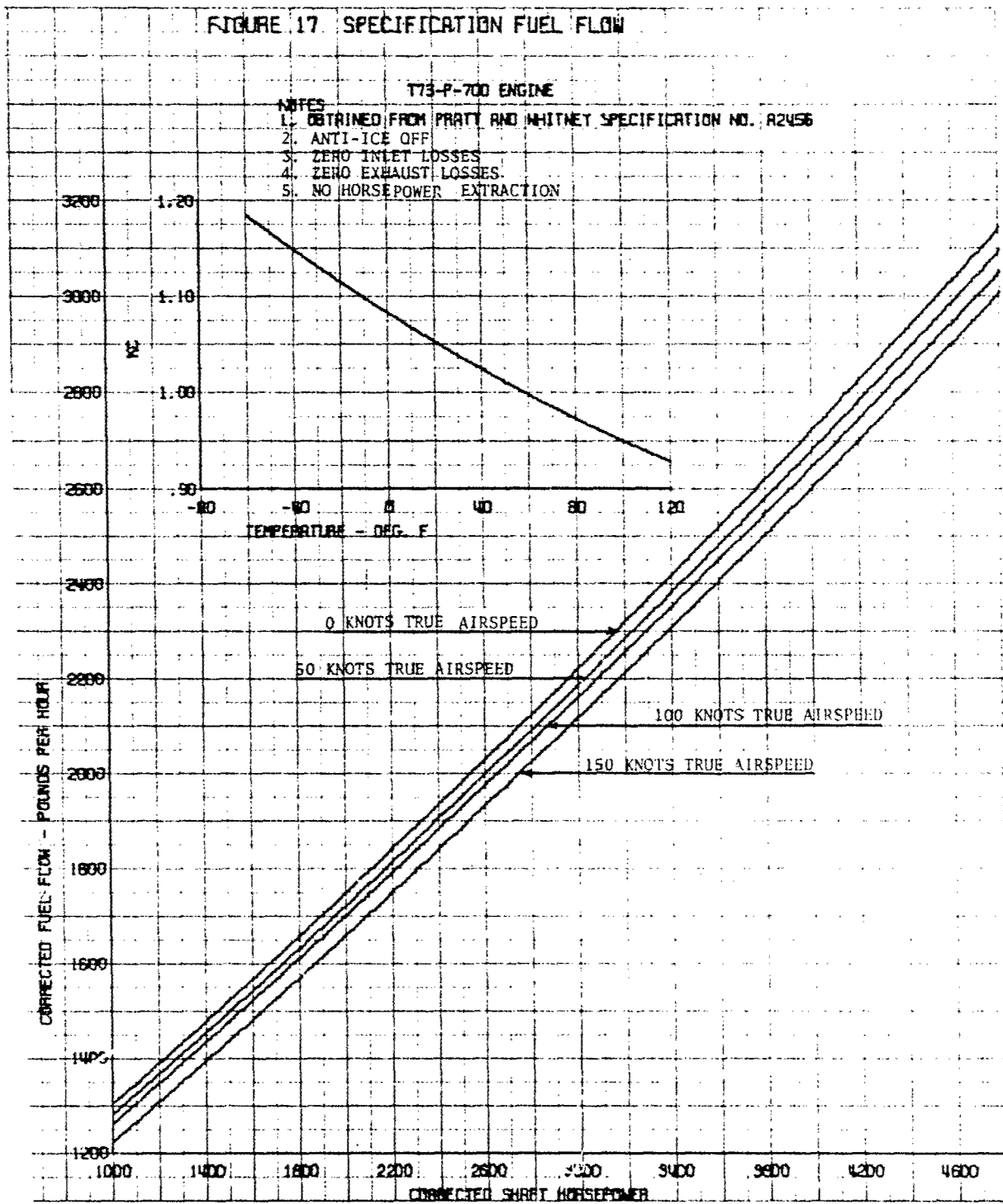


FIGURE 18 LEVEL FLIGHT RANGE SUMMARY  
CH-54B USA S/N 18463

NOTES

1. 5000 FT. STANDARD DAY CONDITIONS
2. ROTOR SPEED = 185 RPM
3. POD OFF - EAPS OFF
4. LINES OBTAINED FROM FIGURES 9 AND 17
5. DATA EXTRAPOLATED FOR GROSS WEIGHTS LESS THAN 30000 POUNDS
6. DASHED LINES DENOTE ESTIMATED SINGLE ENGINE PERFORMANCE

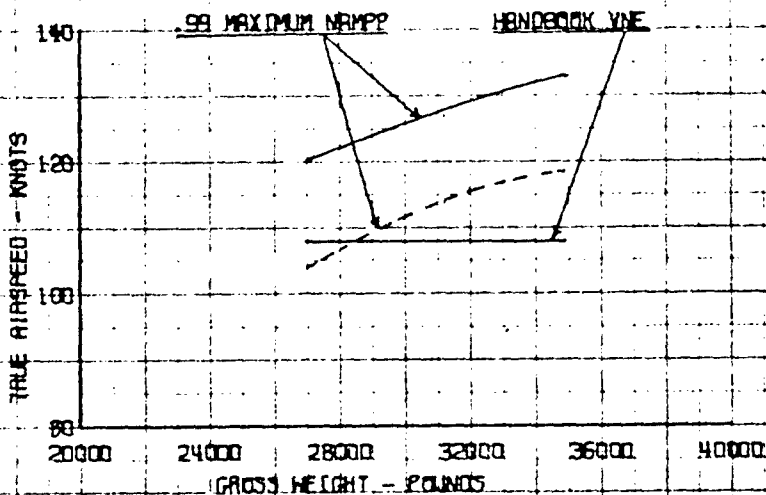
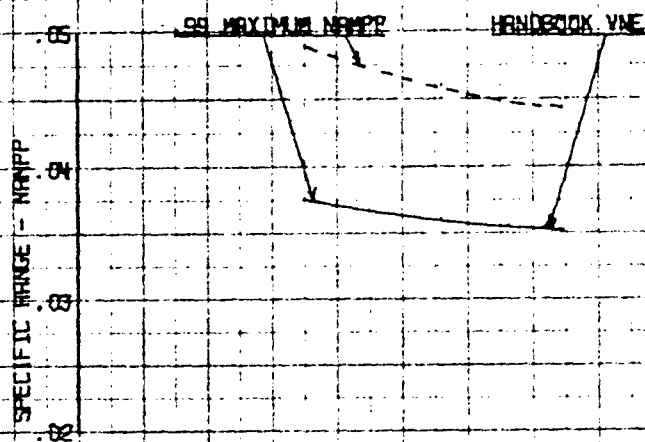


FIGURE 19 ENVELOPE EXPANSION AIRSPEED LIMITATIONS  
CH-53E USA S/N 18463

NOTE  
1. MAXIMUM GROSS WEIGHT - 27000 POUNDS

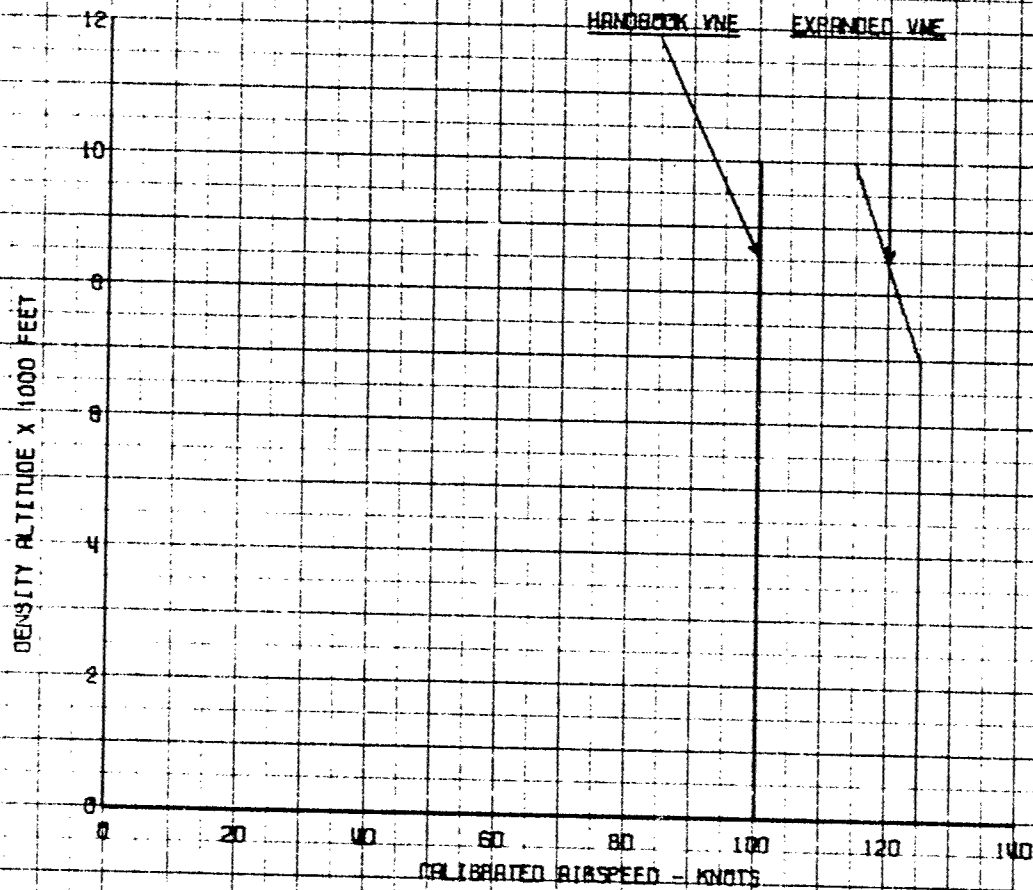




FIGURE 20 VNE EXPANSION  
CH-54B USA S/N 18463

SYMBOL	AVG GROSS WEIGHT (POUNDS)	AVG CG LOCATION (INCHES)	AVG DENSITY ALTITUDE (FEET)	AVG AMBIENT TEMP. (DEG-C)	AVG ROTOR SPEED (RPM)	AVG CW	VNE AIRSPEED (KCS)
▲ CG	26800	333.9(M10)	2910	5.3	1805	.00612	125
	25840	333.9(M10)	5830	0.9	1805	.00840	125
	26710	333.9(M10)	8750	2.1	1805	.00726	119

NOTE

1. POO OFF - EAPS OFF
2. VNE AIRSPEED BASED ON FIGURE 19

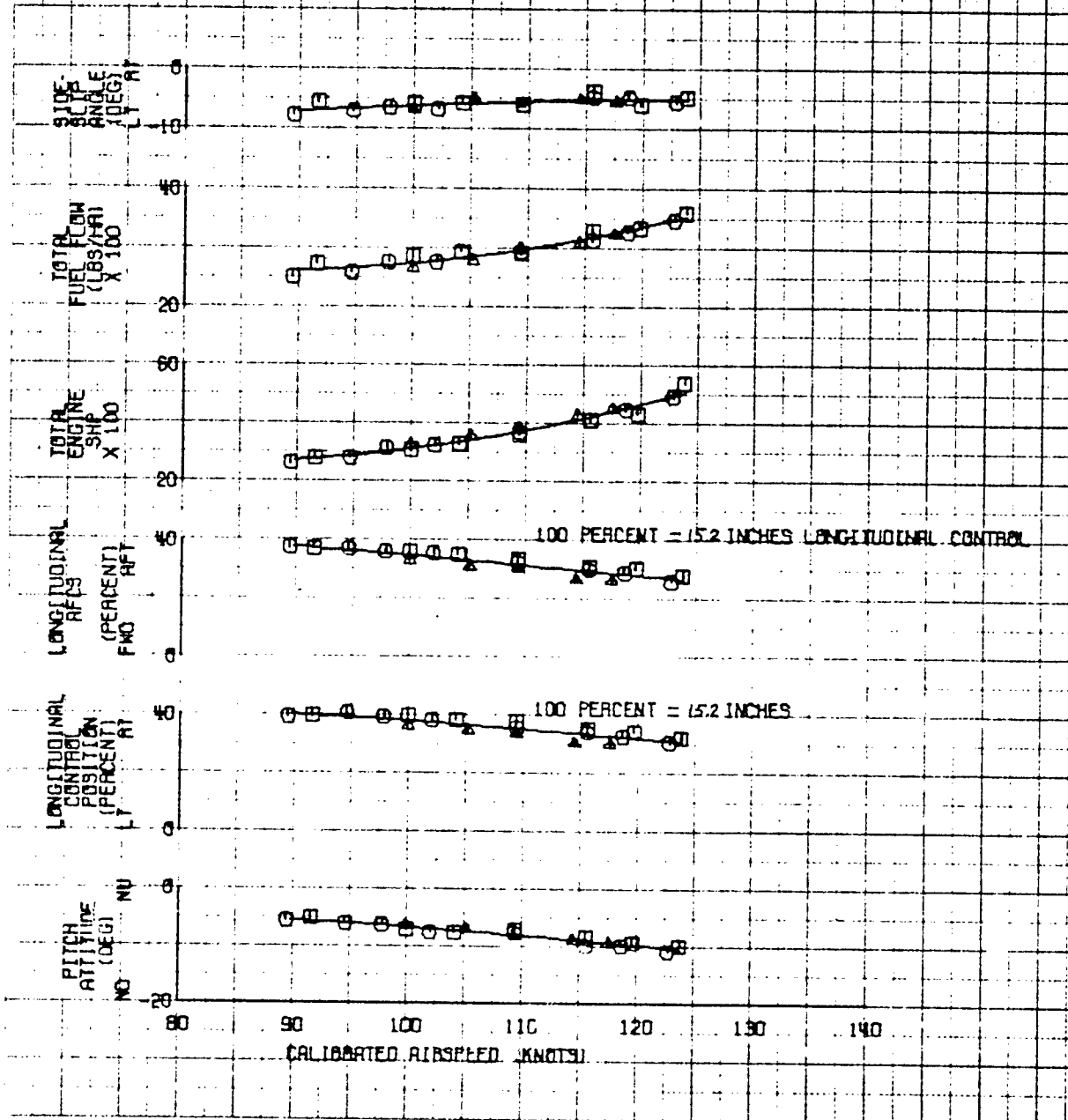


FIGURE 21 VIBRATION CHARACTERISTICS  
CH-54B USA S/N 18463

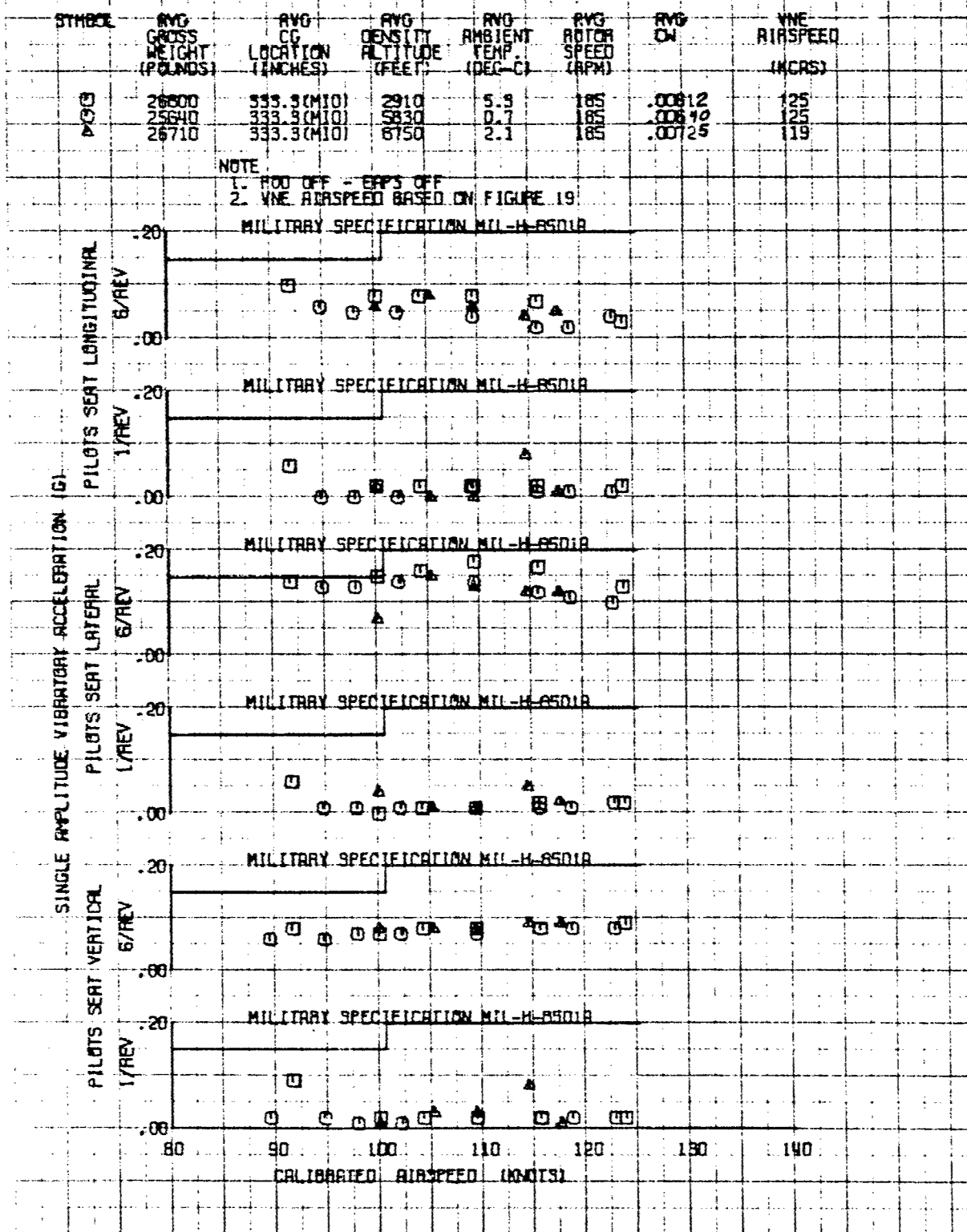


FIGURE 22 VIBRATION CHARACTERISTICS  
CH-54B USA S/N 18463

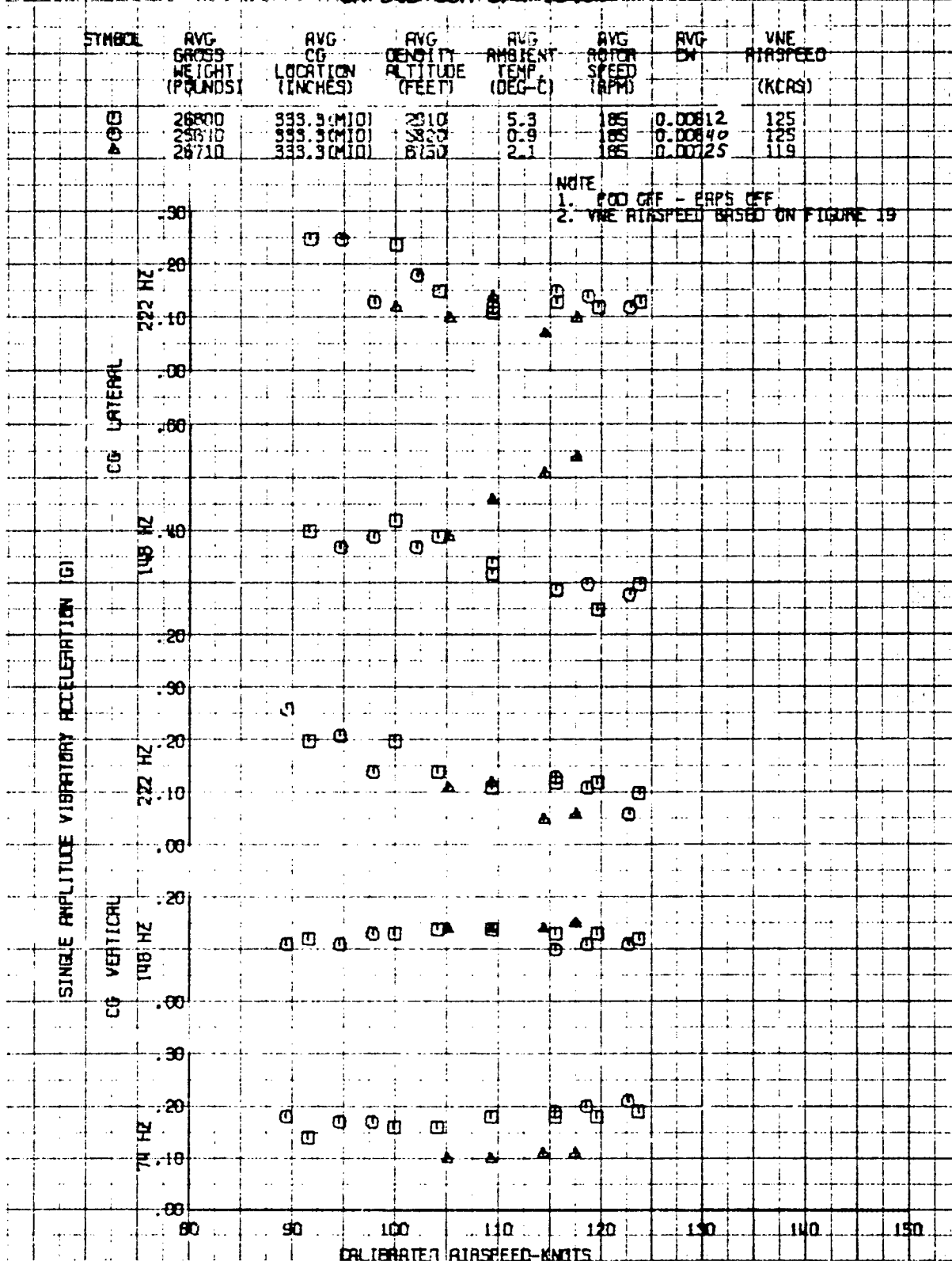


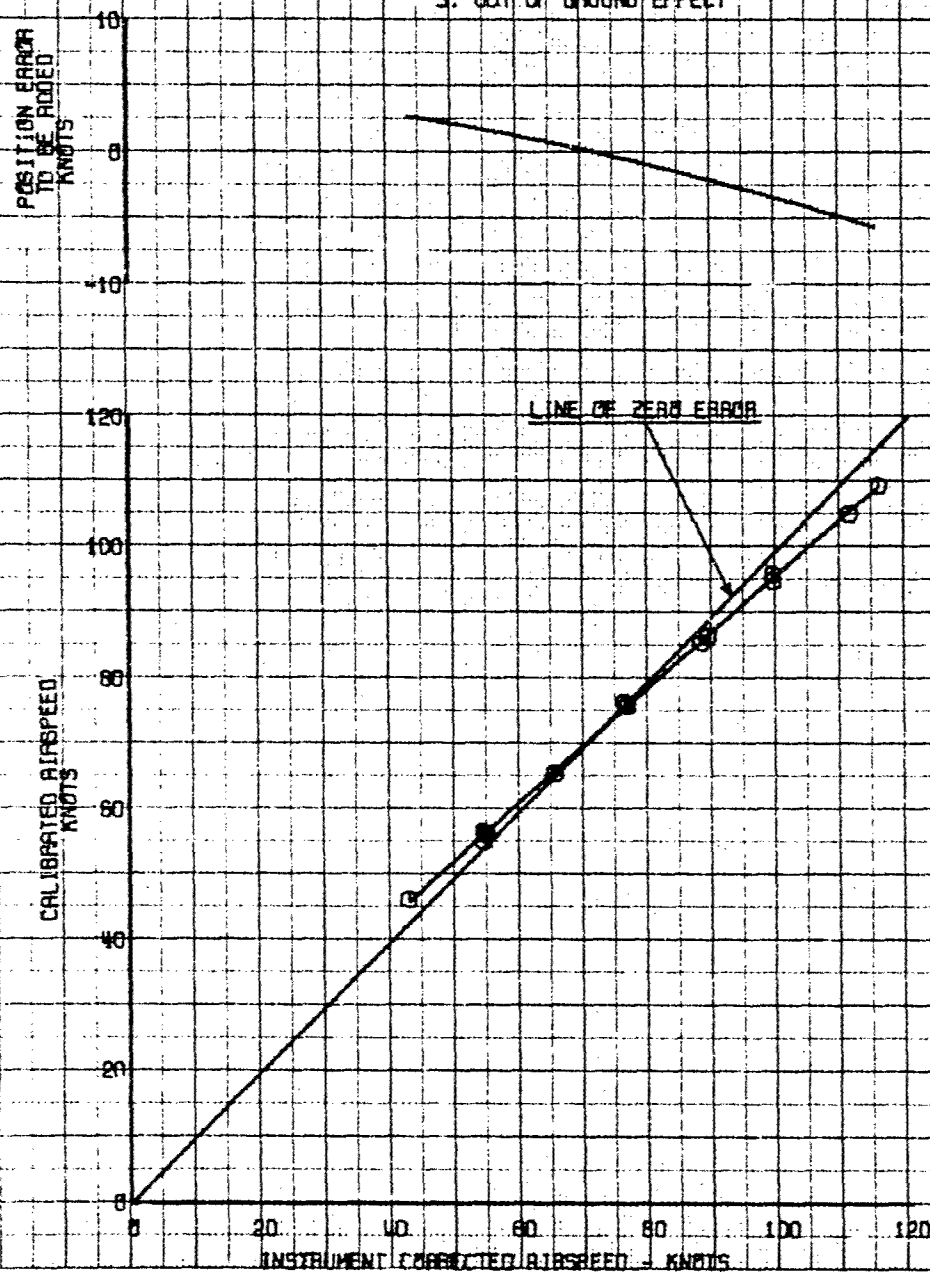
FIGURE 23 AIRSPEED CALIBRATION  
CH-54B USA S/N 18463

SHIPS SYSTEM

AVG GROSS WEIGHT (POUNDS)	AVG CG (INCHES)	AVG DENSITY ALTITUDE (FEET)	AVG OAT (DEG C)	AVG ROTOR SPEED (RPM)	AVG CW
26740	334.2(MID)	5540	7.0	185	.00861

NOTE

1. COPILOTS INDICATOR
2. TRAILING BOMB CALIBRATION METHOD
3. FOD OFF - EAPS OFF
4. LEVEL FLIGHT CONDITION
5. OUT OF GROUND EFFECT



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13. ABSTRACT			
<p>The United States Army Aviation Systems Test Activity conducted a limited performance evaluation and airspeed envelope expansion of the Sikorsky CH-54B (Tarhe) helicopter at Edwards Air Force Base and Bishop, California, during the period 25 October to 22 November 1972. Hover performance, level flight performance, airspeed calibration, and envelope expansion testing were conducted without the engine air particle separator installed. Testing required 13.6 productive flight hours. At takeoff power, the standard-day out-of-ground-effect and in-ground-effect (10-foot) hover ceilings were 6600 and 9050 feet, respectively, at maximum gross weight (47,000 pounds). The hover ceiling on a 35°C day, in ground effect, was 4900 feet at maximum gross weight. Level flight performance was obtained over a gross weight range of 26,070 to 29,990 pounds and a density altitude range of 5580 to 11,580 feet. The airspeed for best endurance was nominally 65 knots true airspeed and the never-exceed airspeed (101 knots calibrated airspeed) was the long-range cruise speed. A 33-percent increase in specific range could be achieved by operating with one engine after reaching cruise altitude. Airspeeds up to 125 knots calibrated airspeed were flown during the level flight, unaccelerated airspeed envelope expansion with no undesirable aircraft characteristics. No deficiencies or shortcomings were observed. The winch load indication system installed in the CH-54B enhanced sling load operations and should be installed in all cargo helicopters with a sling load capability. Further testing is recommended to obtain performance data with the engine air particle separator installed and to determine stability and control characteristics, structural loads, and fatigue life of dynamic components at airspeeds above the current never-exceed airspeed (101 knots calibrated airspeed).</p>			

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		ROLE	WT	ROLE	WT	ROLE	WT
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